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Preface to Microbiology for Allied Health Students Lab Manual

preface

Preface to *Microbiology for Allied Health Students Lab Manual*

This lab manual was created to support a microbiology course for allied health students. The first section of the manual was adapted from the OpenStax *Microbiology* textbook, of which a remixed version, *Microbiology for Allied Health Students*, is used as the text for the course.

The next section, staining methods, encompasses three essential staining procedures used in any microbiology lab.

The manual concludes with descriptions of the major biochemical tests students must perform in order to identify an unknown microorganism. While many traditional lab manuals are lengthy and comprehensive, descriptions of the labs in this manual are kept minimal to encourage students to further research the procedures and results on their own.

The appendix includes a safety contract that each student must sign and submit to the instructor at the beginning of the semester.

This manual was created in partial fulfillment of a grant from the University System of Georgia's Affordable Learning Georgia Textbook Transformation initiative.

Special thanks go to Sara Selby for editing and photography.

Molly Smith

2017

Gram Stain Procedure

Procedure for doing a gram stain

Gram Stain Procedure

Preparation of microscope slide:

1. Clean slide with a Kimwipe and alcohol to remove any fingerprints.
2. Draw two circles with your Sharpie on the **bottom** of the slide.
3. Using your inoculation loop, put two **small** drops of water in each circle.
4. Using aseptic technique, remove a **very small** amount of bacteria from the culture tube. Make sure you flame the tube before and after you enter.
5. Smear the bacteria in the drop of water on your slide. You may go out of the perimeter of your circles!
6. Let the slide **air dry completely**.
7. Heat-fix the slide by running it through the flame 3-4 times with the 'smear' side up. Do not flame the side with the bacteria!
8. Let the slide cool completely and you are ready to stain it.

Staining procedure:

1. At the back sinks, place **crystal violet** on each smear for 1 minute.
2. Rinse the crystal violet off of the slide by swishing the slide gently in the large beakers labeled 'Crystal Violet'.
3. Tap slide on paper towel to remove most of the water.
4. Place **Gram's iodine** on each smear for 1 minute.
5. Rinse by running water from the tap very slowly over the surface of the slide while holding it at an angle.
6. Tap slide on paper towel to remove most of the water.
7. Place **ethanol** on each smear and for 15-30 seconds. This is the most variable step.
8. Rinse with water and tap dry.
9. Place **safranin** on each smear for 1 minute.
10. Rinse with water and tap dry.
11. Blot *gently* with bibulous paper.

12. Dry the bottom of the slide before placing it on the stage of the microscope and view with the oil immersion lens.

Endospore Stain Procedure

Procedure for doing an endospore stain.

Endospore Stain Procedure

Preparation of microscope slide:

1. Clean slide with a Kimwipe and alcohol to remove any fingerprints.
2. Draw two circles with your Sharpie on the **bottom** of the slide.
3. Using your inoculation loop, put two **small** drops of water in each circle.
4. Using aseptic technique, remove a **very small** amount of bacteria from the culture tube. Make sure you flame the tube before and after you enter.
5. Smear the bacteria in the drop of water on your slide. You may go out of the perimeter of your circles!
6. Let the slide **air dry completely**.
7. Heat-fix the slide by running it through the flame 3-4 times with the 'smear' side up. Do not flame the side with the bacteria!
8. Let the slide cool completely and you are ready to stain it.

Staining procedure:

1. Cover the smears with a piece of paper towel within the border of the slide.
2. Place the slide over a beaker of steaming water. Do not let the beaker boil dry!
3. Flood the paper towel with **malachite green** and let the slide steam for 3-5 minutes.
4. Complete the rest of the procedure at the back sinks.
5. Remove the stained paper towel and discard it in the trash can, not in the sinks.
6. Gently rinse the slide with water to remove any pieces of loose paper towel and tap dry.
7. Counterstain with **safranin** for 1 minute.
8. Rinse with water and tap dry.
9. Blot *gently* with bibulous paper.

10. Dry the bottom of the slide before placing it on the stage of the microscope and view with the oil immersion lens.

Acid-fast Stain Procedure

Procedure for doing an acid-fast stain.

Acid-fast Stain Procedure

Preparation of microscope slide:

1. Clean slide with a Kimwipe and alcohol to remove any fingerprints.
2. Draw two circles with your Sharpie on the **bottom** of the slide.
3. Using your inoculation loop, put two **small** drops of water in each circle.
4. Using aseptic technique, remove a **very small** amount of bacteria from the culture tube. Make sure you flame the tube before and after you enter.
5. Smear the bacteria in the drop of water on your slide. You may go out of the perimeter of your circles!
6. Let the slide **air dry completely**.
7. Heat-fix the slide by running it through the flame 3-4 times with the 'smear' side up. Do not flame the side with the bacteria!
8. Let the slide cool completely and you are ready to stain it.

Staining procedure:

1. Cover the smears with a piece of paper towel within the border of the slide.
2. Place the slide over a beaker of steaming water. Do not let the beaker boil dry!
3. Flood the paper towel with **carbolfuchsin** and let the slide steam for 3-5 minutes.
4. Complete the rest of the procedure at the back sinks.
5. Remove the stained paper towel and discard it in the trash can, not in the sinks.
6. Gently rinse the slide with water to remove any pieces of loose paper towel and tap dry.
7. Apply **acid-alcohol** for 15-30 seconds.
8. Rinse off and tap dry.
9. Counterstain with **methylene blue** for 1.5 minutes.
10. Rinse with water and tap dry.

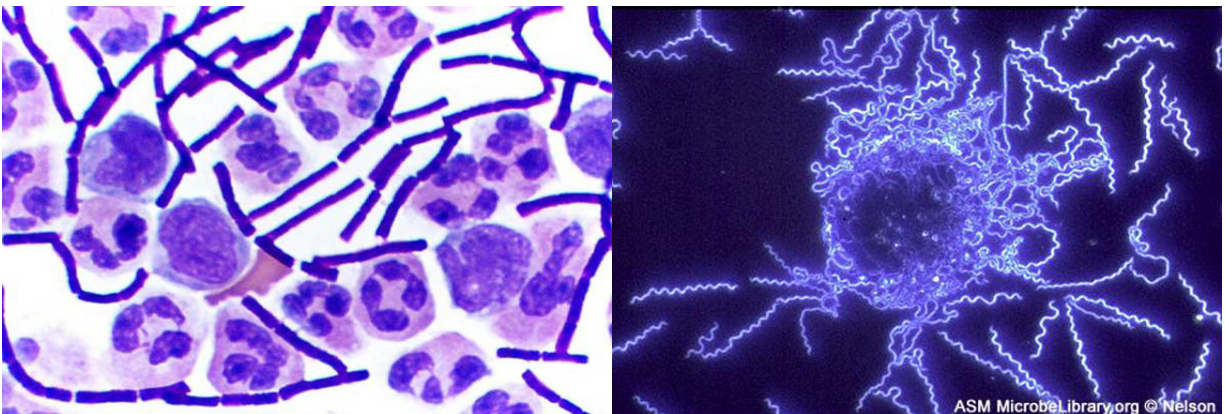
11. Blot *gently* with bibulous paper.
12. Dry the bottom of the slide before placing it on the stage of the microscope and view with the oil immersion lens.

Introduction

class="introduction"

Different types of microscopy are used to visualize different structures. Brightfield microscopy (left) renders a darker image on a lighter background, producing a clear image of these *Bacillus anthracis* cells in cerebrospinal fluid (the rod-shaped bacterial cells are surrounded by larger white blood cells). Darkfield microscopy (right) increases contrast, rendering a brighter

image on a
darker
background,
as
demonstrated
by this image
of the
bacterium
Borrelia
burgdorferi,
which causes
Lyme disease.
(credit left:
modification
of work by
Centers for
Disease
Control and
Prevention;
credit right:
modification
of work by
American
Society for
Microbiology
)



When we look at a rainbow, its colors span the full spectrum of light that the human eye can detect and differentiate. Each hue represents a different frequency of visible light, processed by our eyes and brains and rendered as red, orange, yellow, green, or one of the many other familiar colors that have always been a part of the human experience. But only recently have humans developed an understanding of the properties of light that allow us to see images in color.

Over the past several centuries, we have learned to manipulate light to peer into previously invisible worlds—those too small or too far away to be seen by the naked eye. Through a microscope, we can examine microbial cells and colonies, using various techniques to manipulate color, size, and contrast in ways that help us identify species and diagnose disease.

[\[link\]](#) illustrates how we can apply the properties of light to visualize and magnify images; but these stunning micrographs are just two examples of the numerous types of images we are now able to produce with different microscopic technologies. This chapter explores how various types of microscopes manipulate light in order to provide a window into the world of microorganisms. By understanding how various kinds of microscopes work, we can produce highly detailed images of microbes that can be useful for both research and clinical applications.

The Properties of Light

LEARNING OBJECTIVES

- Identify and define the characteristics of electromagnetic radiation (EMR) used in microscopy
- Explain how lenses are used in microscopy to manipulate visible and ultraviolet (UV) light

Note:

Part 1

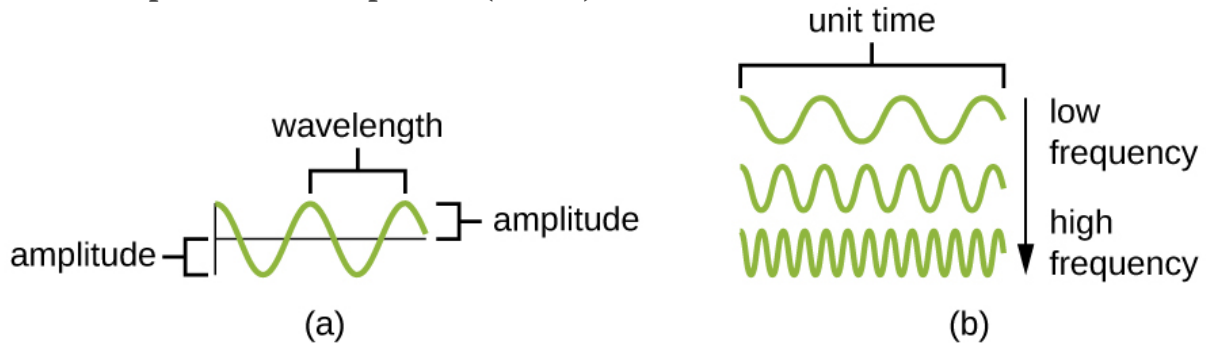
Cindy, a 17-year-old counselor at a summer sports camp, scraped her knee playing basketball 2 weeks ago. At the time, she thought it was only a minor abrasion that would heal, like many others before it. Instead, the wound began to look like an insect bite and has continued to become increasingly painful and swollen.

The camp nurse examines the lesion and observes a large amount of pus oozing from the surface. Concerned that Cindy may have developed a potentially aggressive infection, she swabs the wound to collect a sample from the infection site. Then she cleans out the pus and dresses the wound, instructing Cindy to keep the area clean and to come back the next day. When Cindy leaves, the nurse sends the sample to the closest medical lab to be analyzed under a microscope.

- What are some things we can learn about these bacteria by looking at them under a microscope?

Jump to the [next](#) Clinical Focus box.

Visible light consists of electromagnetic waves that behave like other waves. Hence, many of the properties of light that are relevant to microscopy can be understood in terms of light's behavior as a wave. An important property of light waves is the **wavelength**, or the distance between one peak of a wave and the next peak. The height of each peak (or depth of each trough) is called the **amplitude**. In contrast, the **frequency** of the wave is the rate of vibration of the wave, or the number of wavelengths within a specified time period ([\[link\]](#)).

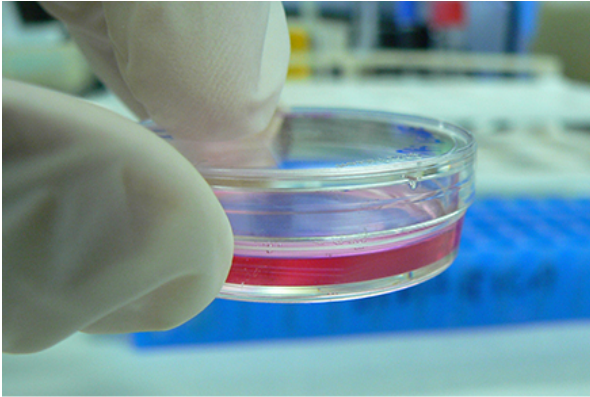


(a) The amplitude is the height of a wave, whereas the wavelength is the distance between one peak and the next. (b) These waves have different frequencies, or rates of vibration. The wave at the top has the lowest frequency, since it has the fewest peaks per unit time. The wave at the bottom has the highest frequency.

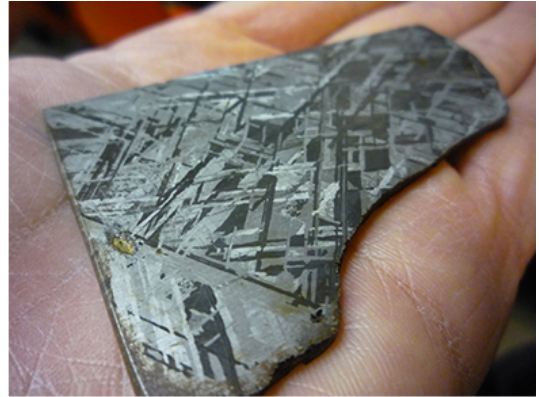
Interactions of Light

Light waves interact with materials by being reflected, absorbed, or transmitted. **Reflection** occurs when a wave bounces off of a material. For example, a red piece of cloth may reflect red light to our eyes while absorbing other colors of light. **Absorbance** occurs when a material captures the energy of a light wave. In the case of glow-in-the-dark plastics, the energy from light can be absorbed and then later re-emitted as another form of phosphorescence. Transmission occurs when a wave travels through a material, like light through glass (the process of transmission is called **transmittance**). When a material allows a large proportion of light to be transmitted, it may do so because it is thinner, or more transparent

(having more **transparency** and less **opacity**). [\[link\]](#) illustrates the difference between transparency and opacity.



(a)



(b)

(a) A Petri dish is made of transparent plastic or glass, which allows transmission of a high proportion of light. This transparency allows us to see through the sides of the dish to view the contents. (b) This slice of an iron meteorite is opaque (i.e., it has opacity). Light is not transmitted through the material, making it impossible to see the part of the hand covered by the object. (credit a: modification of work by Umberto Salvagnin; credit b: modification of work by “Waifer X”/Flickr)

Light waves can also interact with each other by **interference**, creating complex patterns of motion. Dropping two pebbles into a puddle causes the waves on the puddle’s surface to interact, creating complex interference patterns. Light waves can interact in the same way.

In addition to interfering with each other, light waves can also interact with small objects or openings by bending or scattering. This is called **diffraction**. Diffraction is larger when the object is smaller relative to the wavelength of the light (the distance between two consecutive peaks of a

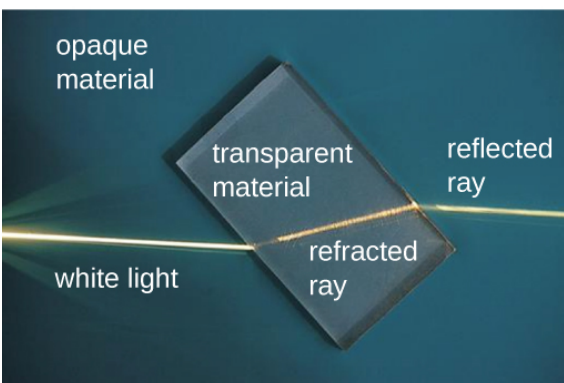
light wave). Often, when waves diffract in different directions around an obstacle or opening, they will interfere with each other.

Note:

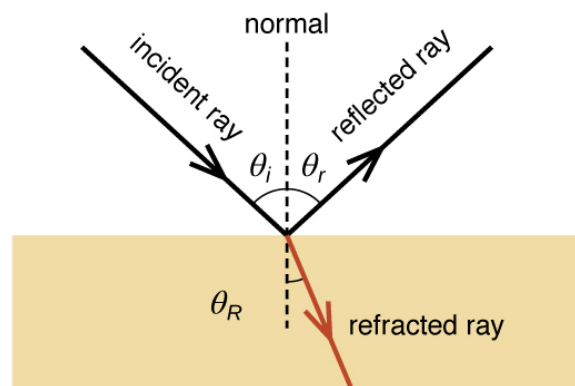
- If a light wave has a long wavelength, is it likely to have a low or high frequency?
- If an object is transparent, does it reflect, absorb, or transmit light?

Lenses and Refraction

In the context of microscopy, **refraction** is perhaps the most important behavior exhibited by light waves. Refraction occurs when light waves change direction as they enter a new medium ([link](#)). Different transparent materials transmit light at different speeds; thus, light can change speed when passing from one material to another. This change in speed usually also causes a change in direction (refraction), with the degree of change dependent on the angle of the incoming light.



(a)



(b)

(a) Refraction occurs when light passes from one medium, such as air, to another, such as glass, changing the direction of the light rays. (b)

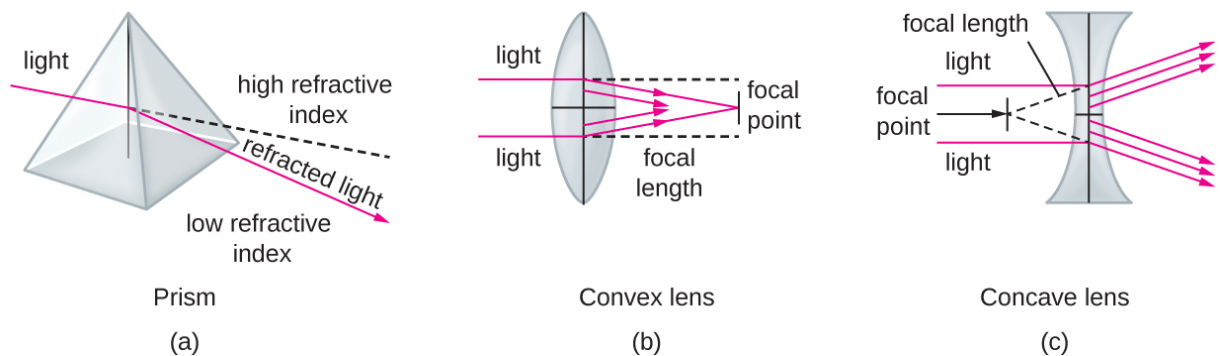
As shown in this diagram, light rays passing from one medium to another may be either refracted or reflected.

The extent to which a material slows transmission speed relative to empty space is called the **refractive index** of that material. Large differences between the refractive indices of two materials will result in a large amount of refraction when light passes from one material to the other. For example, light moves much more slowly through water than through air, so light entering water from air can change direction greatly. We say that the water has a higher refractive index than air ([\[link\]](#)).



This straight pole appears to bend at an angle as it enters the water. This optical illusion is due to the large difference between the refractive indices of air and water.

When light crosses a boundary into a material with a higher refractive index, its direction turns to be closer to perpendicular to the boundary (i.e., more toward a normal to that boundary; see [\[link\]](#)). This is the principle behind lenses. We can think of a lens as an object with a curved boundary (or a collection of prisms) that collects all of the light that strikes it and refracts it so that it all meets at a single point called the **image point (focus)**. A convex lens can be used to magnify because it can focus at closer range than the human eye, producing a larger image. Concave lenses and mirrors can also be used in microscopes to redirect the light path. [\[link\]](#) shows the **focal point** (the image point when light entering the lens is parallel) and the **focal length** (the distance to the focal point) for convex and concave lenses.



- (a) A lens is like a collection of prisms, such as the one shown here.
(b) When light passes through a convex lens, it is refracted toward a focal point on the other side of the lens. The focal length is the distance to the focal point. (c) Light passing through a concave lens is refracted away from a focal point in front of the lens.

The human eye contains a lens that enables us to see images. This lens focuses the light reflecting off of objects in front of the eye onto the surface of the retina, which is like a screen in the back of the eye. Artificial lenses placed in front of the eye (contact lenses, glasses, or microscopic lenses) focus light before it is focused (again) by the lens of the eye, manipulating the image that ends up on the retina (e.g., by making it appear larger).

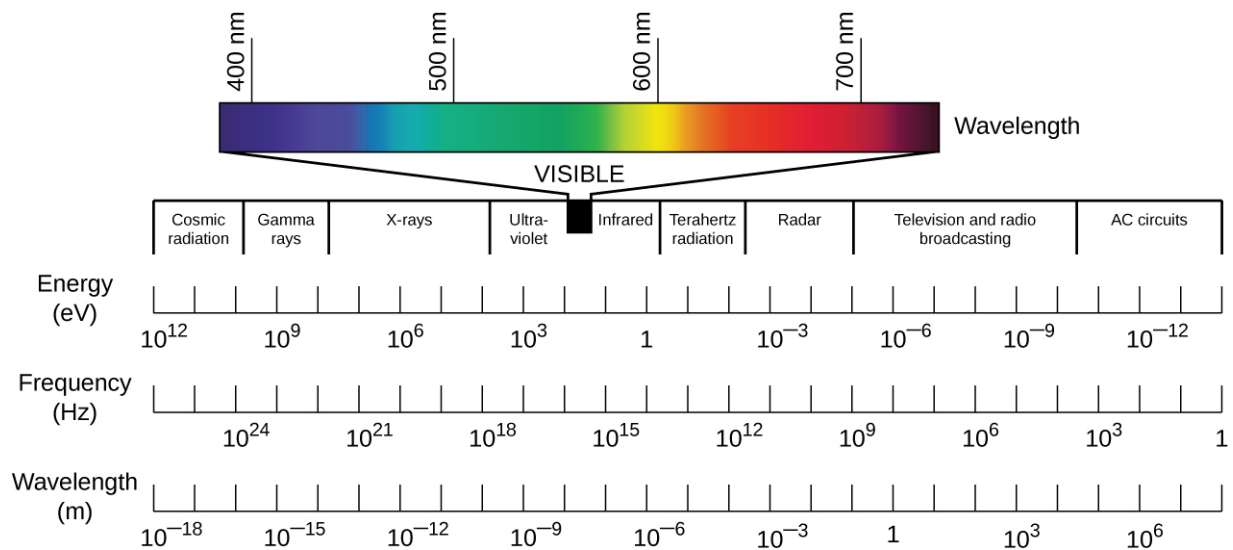
Images are commonly manipulated by controlling the distances between the object, the lens, and the screen, as well as the curvature of the lens. For example, for a given amount of curvature, when an object is closer to the lens, the focal points are farther from the lens. As a result, it is often necessary to manipulate these distances to create a focused image on a screen. Similarly, more curvature creates image points closer to the lens and a larger image when the image is in focus. This property is often described in terms of the focal distance, or distance to the focal point.

Note:

- Explain how a lens focuses light at the image point.
- Name some factors that affect the focal length of a lens.

Electromagnetic Spectrum and Color

Visible light is just one form of electromagnetic radiation (EMR), a type of energy that is all around us. Other forms of EMR include microwaves, X-rays, and radio waves, among others. The different types of EMR fall on the electromagnetic spectrum, which is defined in terms of wavelength and frequency. The spectrum of visible light occupies a relatively small range of frequencies between infrared and ultraviolet light ([\[link\]](#)).



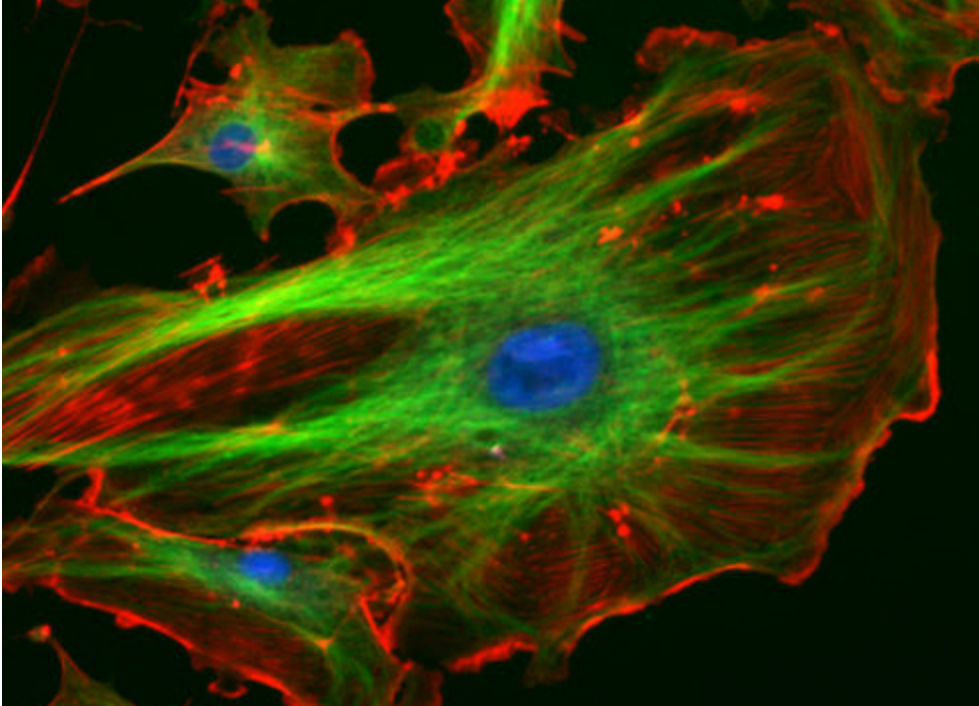
The electromagnetic spectrum ranges from high-frequency gamma rays to low-frequency radio waves. Visible light is the relatively small range of electromagnetic frequencies that can be sensed by the human eye. On the electromagnetic spectrum, visible light falls between ultraviolet and infrared light. (credit: modification of work by Johannes Ahlmann)

Whereas wavelength represents the distance between adjacent peaks of a light wave, frequency, in a simplified definition, represents the rate of oscillation. Waves with higher frequencies have shorter wavelengths and, therefore, have more oscillations per unit time than lower-frequency waves. Higher-frequency waves also contain more energy than lower-frequency waves. This energy is delivered as elementary particles called photons. Higher-frequency waves deliver more energetic photons than lower-frequency waves.

Photons with different energies interact differently with the retina. In the spectrum of visible light, each color corresponds to a particular frequency and wavelength ([\[link\]](#)). The lowest frequency of visible light appears as the color red, whereas the highest appears as the color violet. When the retina receives visible light of many different frequencies, we perceive this as white light. However, white light can be separated into its component colors

using refraction. If we pass white light through a prism, different colors will be refracted in different directions, creating a rainbow-like spectrum on a screen behind the prism. This separation of colors is called **dispersion**, and it occurs because, for a given material, the refractive index is different for different frequencies of light.

Certain materials can refract nonvisible forms of EMR and, in effect, transform them into visible light. Certain **fluorescent** dyes, for instance, absorb ultraviolet or blue light and then use the energy to emit photons of a different color, giving off light rather than simply vibrating. This occurs because the energy absorption causes electrons to jump to higher energy states, after which they then almost immediately fall back down to their ground states, emitting specific amounts of energy as photons. Not all of the energy is emitted in a given photon, so the emitted photons will be of lower energy and, thus, of lower frequency than the absorbed ones. Thus, a dye such as Texas red may be excited by blue light, but emit red light; or a dye such as fluorescein isothiocyanate (FITC) may absorb (invisible) high-energy ultraviolet light and emit green light ([\[link\]](#)). In some materials, the photons may be emitted following a delay after absorption; in this case, the process is called **phosphorescence**. Glow-in-the-dark plastic works by using phosphorescent material.



The fluorescent dyes absorbed by these bovine pulmonary artery endothelial cells emit brilliant colors when excited by ultraviolet light under a fluorescence microscope. Various cell structures absorb different dyes. The nuclei are stained blue with 4',6-diamidino-2-phenylindole (DAPI); microtubules are marked green by an antibody bound to FITC; and actin filaments are labeled red with phalloidin bound to tetramethylrhodamine (TRITC). (credit: National Institutes of Health)

Note:

- Which has a higher frequency: red light or green light?
- Explain why dispersion occurs when white light passes through a prism.

- Why do fluorescent dyes emit a different color of light than they absorb?

Magnification, Resolution, and Contrast

Microscopes magnify images and use the properties of light to create useful images of small objects. **Magnification** is defined as the ability of a lens to enlarge the image of an object when compared to the real object. For example, a magnification of $10\times$ means that the image appears 10 times the size of the object as viewed with the naked eye.

Greater magnification typically improves our ability to see details of small objects, but magnification alone is not sufficient to make the most useful images. It is often useful to enhance the **resolution** of objects: the ability to tell that two separate points or objects are separate. A low-resolution image appears fuzzy, whereas a high-resolution image appears sharp. Two factors affect resolution. The first is wavelength. Shorter wavelengths are able to resolve smaller objects; thus, an electron microscope has a much higher resolution than a light microscope, since it uses an electron beam with a very short wavelength, as opposed to the long-wavelength visible light used by a light microscope. The second factor that affects resolution is **numerical aperture**, which is a measure of a lens's ability to gather light. The higher the numerical aperture, the better the resolution.

Note:



Read this [article](#) to learn more about factors that can increase or decrease the numerical aperture of a lens.

Even when a microscope has high resolution, it can be difficult to distinguish small structures in many specimens because microorganisms are relatively transparent. It is often necessary to increase **contrast** to detect different structures in a specimen. Various types of microscopes use different features of light or electrons to increase contrast—visible differences between the parts of a specimen (see [Instruments of Microscopy](#)). Additionally, dyes that bind to some structures but not others can be used to improve the contrast between images of relatively transparent objects (see [Staining Microscopic Specimens](#)).

Note:

- Explain the difference between magnification and resolution.
- Explain the difference between resolution and contrast.
- Name two factors that affect resolution.

Key Concepts and Summary

- Light waves interacting with materials may be **reflected**, **absorbed**, or **transmitted**, depending on the properties of the material.
- Light waves can interact with each other (**interference**) or be distorted by interactions with small objects or openings (**diffraction**).
- **Refraction** occurs when light waves change speed and direction as they pass from one medium to another. Differences in the **refraction indices** of two materials determine the magnitude of directional changes when light passes from one to the other.
- A **lens** is a medium with a curved surface that refracts and focuses light to produce an image.

- Visible light is part of the **electromagnetic spectrum**; light waves of different frequencies and wavelengths are distinguished as colors by the human eye.
- A prism can separate the colors of white light (**dispersion**) because different frequencies of light have different refractive indices for a given material.
- **Fluorescent dyes** and **phosphorescent** materials can effectively transform nonvisible electromagnetic radiation into visible light.
- The power of a microscope can be described in terms of its **magnification** and **resolution**.
- Resolution can be increased by shortening wavelength, increasing the **numerical aperture** of the lens, or using stains that enhance contrast.

Multiple Choice

Exercise:

Problem: Which of the following has the highest energy?

- A. light with a long wavelength
- B. light with an intermediate wavelength
- C. light with a short wavelength
- D. It is impossible to tell from the information given.

Solution:

C

Exercise:

Problem:

You place a specimen under the microscope and notice that parts of the specimen begin to emit light immediately. These materials can be described as _____.

- A. fluorescent

- B. phosphorescent
- C. transparent
- D. opaque

Solution:

A

Fill in the Blank

Exercise:

Problem:

When you see light bend as it moves from air into water, you are observing _____.

Solution:

refraction

Short Answer

Exercise:

Problem:

Explain how a prism separates white light into different colors.

Critical Thinking

Exercise:

Problem: In [\[link\]](#), which of the following has the lowest energy?

- A. visible light
- B. X-rays
- C. ultraviolet rays
- D. infrared rays

Peering Into the Invisible World

LEARNING OBJECTIVES

- Describe historical developments and individual contributions that led to the invention and development of the microscope
- Compare and contrast the features of simple and compound microscopes

Some of the fundamental characteristics and functions of microscopes can be understood in the context of the history of their use. Italian scholar Girolamo Fracastoro is regarded as the first person to formally postulate that disease was spread by tiny invisible *seminaria*, or “seeds of the contagion.” In his book *De Contagione* (1546), he proposed that these seeds could attach themselves to certain objects (which he called *fomes* [cloth]) that supported their transfer from person to person. However, since the technology for seeing such tiny objects did not yet exist, the existence of the *seminaria* remained hypothetical for a little over a century—an invisible world waiting to be revealed.

Early Microscopes

Antonie van Leeuwenhoek, sometimes hailed as “the Father of Microbiology,” is typically credited as the first person to have created microscopes powerful enough to view microbes ([\[link\]](#)). Born in the city of Delft in the Dutch Republic, van Leeuwenhoek began his career selling fabrics. However, he later became interested in lens making (perhaps to look at threads) and his innovative techniques produced microscopes that allowed him to observe microorganisms as no one had before. In 1674, he

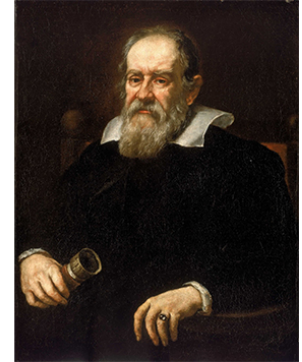
described his observations of single-celled organisms, whose existence was previously unknown, in a series of letters to the Royal Society of London. His report was initially met with skepticism, but his claims were soon verified and he became something of a celebrity in the scientific community.



(a)



(b)



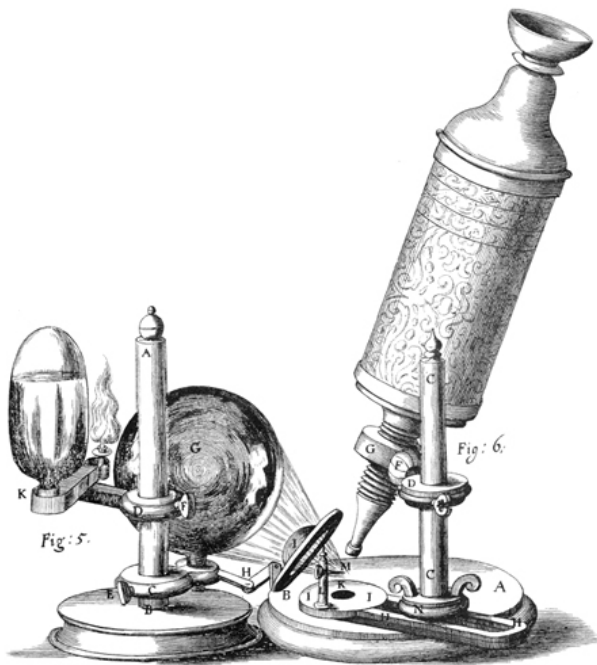
(c)

(a) Antonie van Leeuwenhoek (1632–1723) is credited as being the first person to observe microbes, including bacteria, which he called “animalcules” and “wee little beasties.” (b) Even though van Leeuwenhoek’s microscopes were simple microscopes (as seen in this replica), they were more powerful and provided better resolution than the compound microscopes of his day. (c) Though more famous for developing the telescope, Galileo Galilei (1564–1642) was also one of the pioneers of microscopy. (credit b: modification of work by “Wellcome Images”/Wikimedia Commons)

While van Leeuwenhoek is credited with the discovery of microorganisms, others before him had contributed to the development of the microscope. These included eyeglass makers in the Netherlands in the late 1500s, as well as the Italian astronomer Galileo Galilei, who used a **compound microscope** to examine insect parts ([\[link\]](#)). Whereas van Leeuwenhoek used a **simple microscope**, in which light is passed through just one lens,

Galileo's compound microscope was more sophisticated, passing light through two sets of lenses.

Van Leeuwenhoek's contemporary, the Englishman Robert Hooke (1635–1703), also made important contributions to microscopy, publishing in his book *Micrographia* (1665) many observations using compound microscopes. Viewing a thin sample of cork through his microscope, he was the first to observe the structures that we now know as cells ([link](#)). Hooke described these structures as resembling “Honey-comb,” and as “small Boxes or Bladders of Air,” noting that each “Cavern, Bubble, or Cell” is distinct from the others (in Latin, “cell” literally means “small room”). They likely appeared to Hooke to be filled with air because the cork cells were dead, with only the rigid cell walls providing the structure.



(a)



(b)

Robert Hooke used his (a) compound microscope to view (b) cork cells. Both of these engravings are from his seminal work *Micrographia*, published in 1665.

Note:

- Explain the difference between simple and compound microscopes.
- Compare and contrast the contributions of van Leeuwenhoek, Hooke, and Galileo to early microscopy.

Note:**Who Invented the Microscope?**

While Antonie van Leeuwenhoek and Robert Hooke generally receive much of the credit for early advances in microscopy, neither can claim to be the inventor of the microscope. Some argue that this designation should belong to Hans and Zaccharias Janssen, Dutch spectacle-makers who may have invented the telescope, the simple microscope, and the compound microscope during the late 1500s or early 1600s ([\[link\]](#)). Unfortunately, little is known for sure about the Janssens, not even the exact dates of their births and deaths. The Janssens were secretive about their work and never published. It is also possible that the Janssens did not invent anything at all; their neighbor, Hans Lippershey, also developed microscopes and telescopes during the same time frame, and he is often credited with inventing the telescope. The historical records from the time are as fuzzy and imprecise as the images viewed through those early lenses, and any archived records have been lost over the centuries.

By contrast, van Leeuwenhoek and Hooke can thank ample documentation of their work for their respective legacies. Like Janssen, van Leeuwenhoek began his work in obscurity, leaving behind few records. However, his friend, the prominent physician Reinier de Graaf, wrote a letter to the editor of the *Philosophical Transactions of the Royal Society of London* calling attention to van Leeuwenhoek's powerful microscopes. From 1673 onward, van Leeuwenhoek began regularly submitting letters to the Royal Society detailing his observations. In 1674, his report describing single-celled organisms produced controversy in the scientific community, but his

observations were soon confirmed when the society sent a delegation to investigate his findings. He subsequently enjoyed considerable celebrity, at one point even entertaining a visit by the czar of Russia.

Similarly, Robert Hooke had his observations using microscopes published by the Royal Society in a book called *Micrographia* in 1665. The book became a bestseller and greatly increased interest in microscopy throughout much of Europe.



Zaccharias Janssen, along with his father Hans, may have invented the telescope, the simple microscope, and

the compound microscope during the late 1500s or early 1600s. The historical evidence is inconclusive.

Key Concepts and Summary

- **Antonie van Leeuwenhoek** is credited with the first observation of microbes, including protists and bacteria, with simple microscopes that he made.
- **Robert Hooke** was the first to describe what we now call cells.
- **Simple microscopes** have a single lens, while **compound microscopes** have multiple lenses.

Multiple Choice

Exercise:

Problem: Who was the first to describe “cells” in dead cork tissue?

- A. Hans Janssen
- B. Zaccharias Janssen
- C. Antonie van Leeuwenhoek
- D. Robert Hooke

Solution:

D

Exercise:

Problem: Who is the probable inventor of the compound microscope?

- A. Girolamo Fracastoro
- B. Zaccharias Janssen
- C. Antonie van Leeuwenhoek

D. Robert Hooke

Solution:

B

Fill in the Blank

Exercise:

Problem:

A microscope that uses multiple lenses is called a _____ microscope.

Solution:

compound

Short Answer

Exercise:

Problem:

Why is Antonie van Leeuwenhoek's work much better known than that of Zaccharias Janssen?

Exercise:

Problem:

Why did the cork cells observed by Robert Hooke appear to be empty, as opposed to being full of other structures?

Instruments of Microscopy

LEARNING OBJECTIVES

- Identify and describe the parts of a brightfield microscope
- Calculate total magnification for a compound microscope
- Describe the distinguishing features and typical uses for various types of light microscopes, electron microscopes, and scanning probe microscopes

The early pioneers of microscopy opened a window into the invisible world of microorganisms. But microscopy continued to advance in the centuries that followed. In 1830, Joseph Jackson Lister created an essentially modern light microscope. The 20th century saw the development of microscopes that leveraged nonvisible light, such as fluorescence microscopy, which uses an ultraviolet light source, and electron microscopy, which uses short-wavelength electron beams. These advances led to major improvements in magnification, resolution, and contrast. By comparison, the relatively rudimentary microscopes of van Leeuwenhoek and his contemporaries were far less powerful than even the most basic microscopes in use today. In this section, we will survey the broad range of modern microscopic technology and common applications for each type of microscope.

Light Microscopy

Many types of microscopes fall under the category of light microscopes, which use light to visualize images. Examples of light microscopes include brightfield microscopes, darkfield microscopes, phase-contrast microscopes, differential interference contrast microscopes, fluorescence

microscopes, confocal scanning laser microscopes, and two-photon microscopes. These various types of light microscopes can be used to complement each other in diagnostics and research.

Brightfield Microscopes

The **brightfield microscope**, perhaps the most commonly used type of microscope, is a compound microscope with two or more lenses that produce a dark image on a bright background. Some brightfield microscopes are **monocular** (having a single eyepiece), though most newer brightfield microscopes are **binocular** (having two eyepieces), like the one shown in [\[link\]](#); in either case, each eyepiece contains a lens called an **ocular lens**. The ocular lenses typically magnify images 10 times ($10\times$). At the other end of the body tube are a set of **objective lenses** on a rotating nosepiece. The magnification of these objective lenses typically ranges from $4\times$ to $100\times$, with the magnification for each lens designated on the metal casing of the lens. The ocular and objective lenses work together to create a magnified image. The **total magnification** is the product of the ocular magnification times the objective magnification:

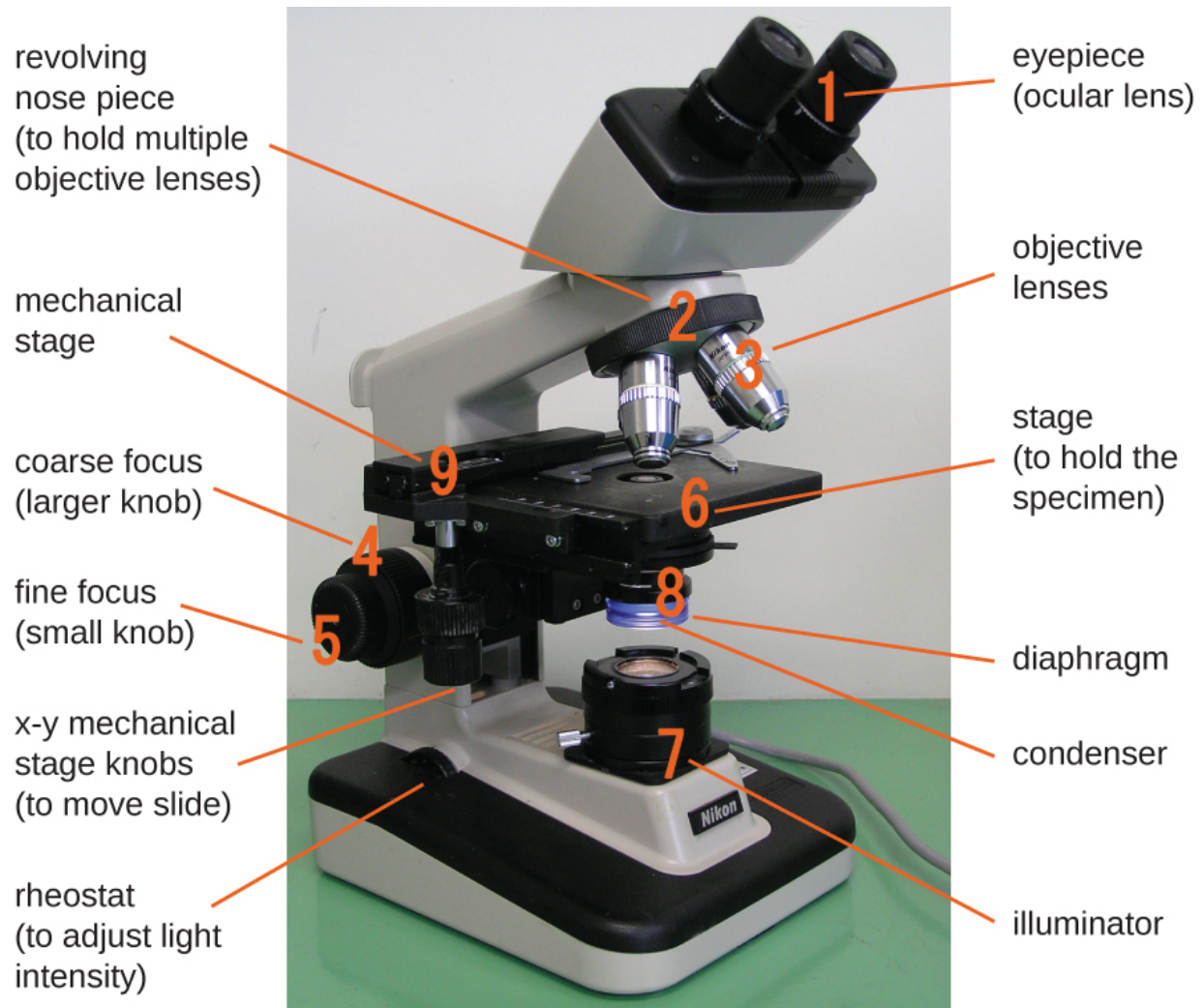
Equation:

$$\text{ocular magnification} \times \text{objective magnification}$$

For example, if a $40\times$ objective lens is selected and the ocular lens is $10\times$, the total magnification would be

Equation:

$$(40\times)(10\times) = 400\times$$



Components of a typical brightfield microscope.

The item being viewed is called a specimen. The specimen is placed on a glass slide, which is then clipped into place on the **stage** (a platform) of the microscope. Once the slide is secured, the specimen on the slide is positioned over the light using the **x-y mechanical stage knobs**. These knobs move the slide on the surface of the stage, but do not raise or lower the stage. Once the specimen is centered over the light, the stage position can be raised or lowered to focus the image. The **coarse focusing knob** is used for large-scale movements with 4× and 10× objective lenses; the **fine**

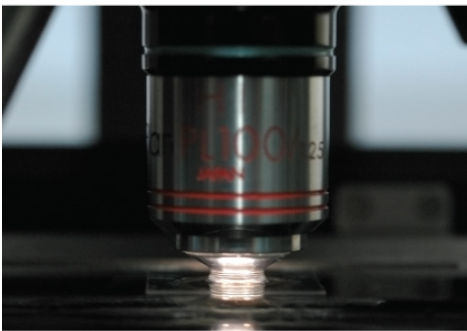
focusing knob is used for small-scale movements, especially with 40× or 100× objective lenses.

When images are magnified, they become dimmer because there is less light per unit area of image. Highly magnified images produced by microscopes, therefore, require intense lighting. In a brightfield microscope, this light is provided by an **illuminator**, which is typically a high-intensity bulb below the stage. Light from the illuminator passes up through **condenser lens** (located below the stage), which focuses all of the light rays on the specimen to maximize illumination. The position of the condenser can be optimized using the attached condenser focus knob; once the optimal distance is established, the condenser should not be moved to adjust the brightness. If less-than-maximal light levels are needed, the amount of light striking the specimen can be easily adjusted by opening or closing a **diaphragm** between the condenser and the specimen. In some cases, brightness can also be adjusted using the **rheostat**, a dimmer switch that controls the intensity of the illuminator.

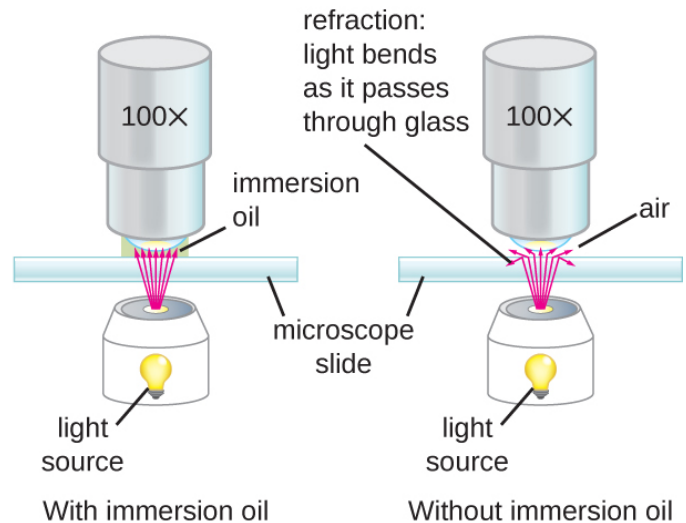
A brightfield microscope creates an image by directing light from the illuminator at the specimen; this light is differentially transmitted, absorbed, reflected, or refracted by different structures. Different colors can behave differently as they interact with **chromophores** (pigments that absorb and reflect particular wavelengths of light) in parts of the specimen. Often, chromophores are artificially added to the specimen using stains, which serve to increase contrast and resolution. In general, structures in the specimen will appear darker, to various extents, than the bright background, creating maximally sharp images at magnifications up to about 1000×. Further magnification would create a larger image, but without increased resolution. This allows us to see objects as small as bacteria, which are visible at about 400× or so, but not smaller objects such as viruses.

At very high magnifications, resolution may be compromised when light passes through the small amount of air between the specimen and the lens. This is due to the large difference between the refractive indices of air and glass; the air scatters the light rays before they can be focused by the lens. To solve this problem, a drop of oil can be used to fill the space between the specimen and an **oil immersion lens**, a special lens designed to be used

with immersion oils. Since the oil has a refractive index very similar to that of glass, it increases the maximum angle at which light leaving the specimen can strike the lens. This increases the light collected and, thus, the resolution of the image ([link](#)). A variety of oils can be used for different types of light.



(a)



(b)

- (a) Oil immersion lenses like this one are used to improve resolution.
(b) Because immersion oil and glass have very similar refractive indices, there is a minimal amount of refraction before the light reaches the lens. Without immersion oil, light scatters as it passes through the air above the slide, degrading the resolution of the image.

Note:

Microscope Maintenance: Best Practices

Even a very powerful microscope cannot deliver high-resolution images if it is not properly cleaned and maintained. Since lenses are carefully designed and manufactured to refract light with a high degree of precision, even a slightly dirty or scratched lens will refract light in unintended ways,

degrading the image of the specimen. In addition, microscopes are rather delicate instruments, and great care must be taken to avoid damaging parts and surfaces. Among other things, proper care of a microscope includes the following:

- cleaning the lenses with lens paper
- not allowing lenses to contact the slide (e.g., by rapidly changing the focus)
- protecting the bulb (if there is one) from breakage
- not pushing an objective into a slide
- not using the coarse focusing knob when using the 40 $\times$ or greater objective lenses
- only using immersion oil with a specialized oil objective, usually the 100 $\times$ objective
- cleaning oil from immersion lenses after using the microscope
- cleaning any oil accidentally transferred from other lenses
- covering the microscope or placing it in a cabinet when not in use

Note:



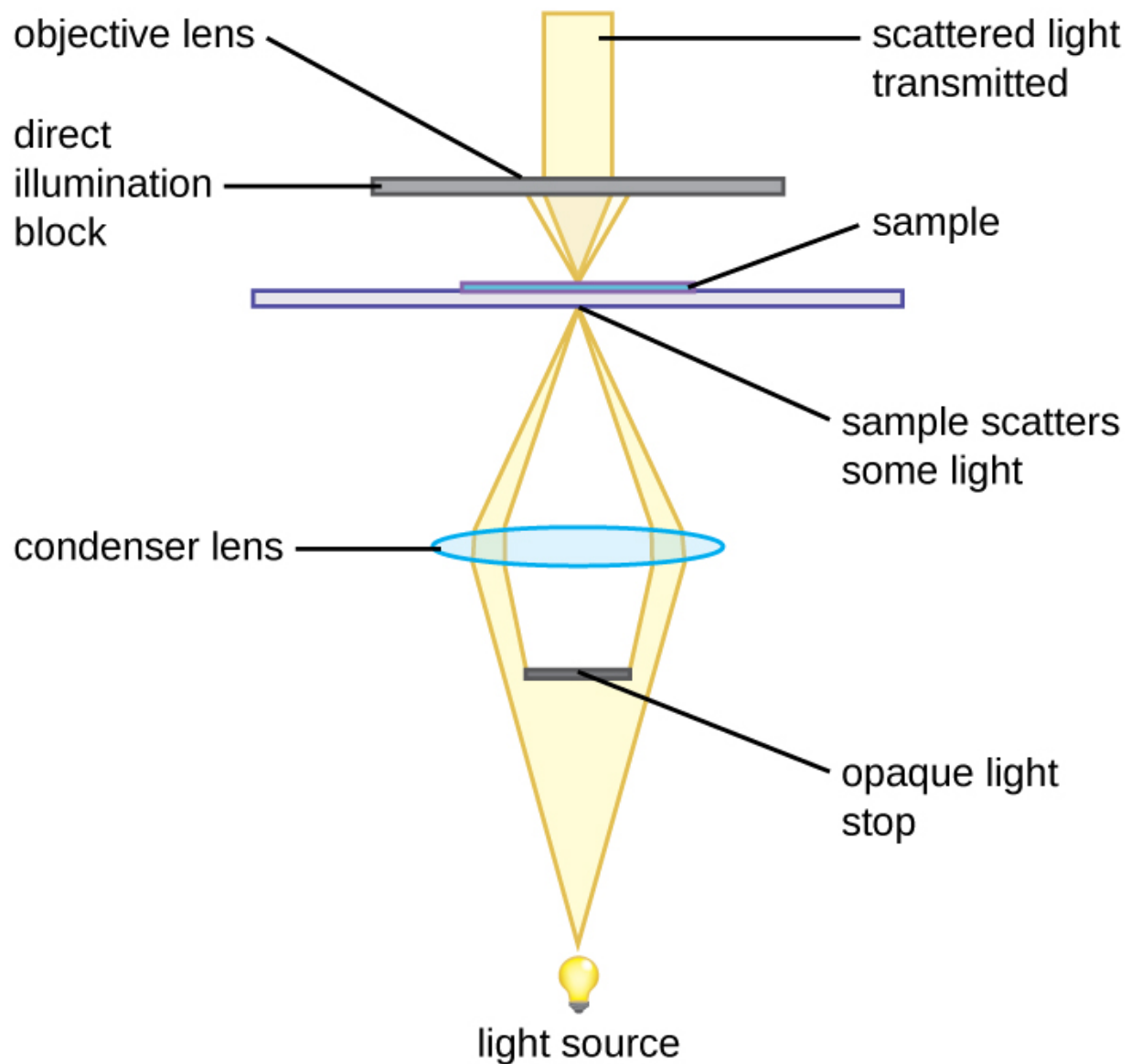
Visit the online resources linked below for simulations and demonstrations involving the use of microscopes. Keep in mind that execution of specific techniques and procedures can vary depending on the specific instrument you are using. Thus, it is important to learn and practice with an actual microscope in a laboratory setting under expert supervision.

- University of Delaware's [Virtual Microscope](#)

- St. John's University [Microscope Tutorials](#)

Darkfield Microscopy

A **darkfield microscope** is a brightfield microscope that has a small but significant modification to the condenser. A small, opaque disk (about 1 cm in diameter) is placed between the illuminator and the condenser lens. This opaque light stop, as the disk is called, blocks most of the light from the illuminator as it passes through the condenser on its way to the objective lens, producing a hollow cone of light that is focused on the specimen. The only light that reaches the objective is light that has been refracted or reflected by structures in the specimen. The resulting image typically shows bright objects on a dark background ([\[link\]](#)).



An opaque light stop inserted into a brightfield microscope is used to produce a darkfield image. The light stop blocks light traveling directly from the illuminator to the objective lens, allowing only light reflected or refracted off the specimen to reach the eye.

Darkfield microscopy can often create high-contrast, high-resolution images of specimens without the use of stains, which is particularly useful for viewing live specimens that might be killed or otherwise compromised by the stains. For example, thin spirochetes like *Treponema pallidum*, the

causative agent of syphilis, can be best viewed using a darkfield microscope ([link](#)).



Use of a darkfield microscope allows us to view living, unstained samples of the spirochete *Treponema pallidum*.

Similar to a photographic negative, the spirochetes appear bright against a dark background. (credit: Centers for Disease Control and Prevention)

Note:

- Identify the key differences between brightfield and darkfield microscopy.

Note:**Part 2**

Wound infections like Cindy's can be caused by many different types of bacteria, some of which can spread rapidly with serious complications. Identifying the specific cause is very important to select a medication that can kill or stop the growth of the bacteria.

After calling a local doctor about Cindy's case, the camp nurse sends the sample from the wound to the closest medical laboratory. Unfortunately, since the camp is in a remote area, the nearest lab is small and poorly equipped. A more modern lab would likely use other methods to culture, grow, and identify the bacteria, but in this case, the technician decides to make a wet mount from the specimen and view it under a brightfield microscope. In a wet mount, a small drop of water is added to the slide, and a cover slip is placed over the specimen to keep it in place before it is positioned under the objective lens.

Under the brightfield microscope, the technician can barely see the bacteria cells because they are nearly transparent against the bright background. To increase contrast, the technician inserts an opaque light stop above the illuminator. The resulting darkfield image clearly shows that the bacteria cells are spherical and grouped in clusters, like grapes.

- Why is it important to identify the shape and growth patterns of cells in a specimen?
- What other types of microscopy could be used effectively to view this specimen?

Jump to the [next](#) Clinical Focus box. Go back to the [previous](#) Clinical Focus box.

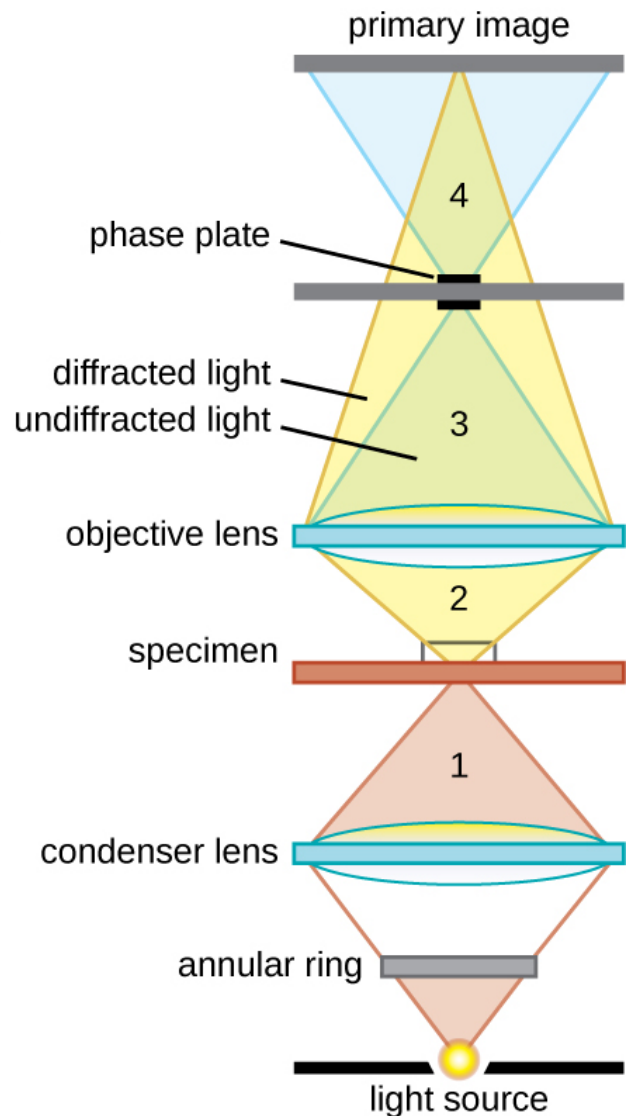
Phase-Contrast Microscopes

Phase-contrast microscopes use refraction and interference caused by structures in a specimen to create high-contrast, high-resolution images without staining. It is the oldest and simplest type of microscope that creates an image by altering the wavelengths of light rays passing through the specimen. To create altered wavelength paths, an annular stop is used in

the condenser. The annular stop produces a hollow cone of light that is focused on the specimen before reaching the objective lens. The objective contains a phase plate containing a phase ring. As a result, light traveling directly from the illuminator passes through the phase ring while light refracted or reflected by the specimen passes through the plate. This causes waves traveling through the ring to be about one-half of a wavelength out of phase with those passing through the plate. Because waves have peaks and troughs, they can add together (if in phase together) or cancel each other out (if out of phase). When the wavelengths are out of phase, wave troughs will cancel out wave peaks, which is called destructive interference. Structures that refract light then appear dark against a bright background of only unrefracted light. More generally, structures that differ in features such as refractive index will differ in levels of darkness ([\[link\]](#)).

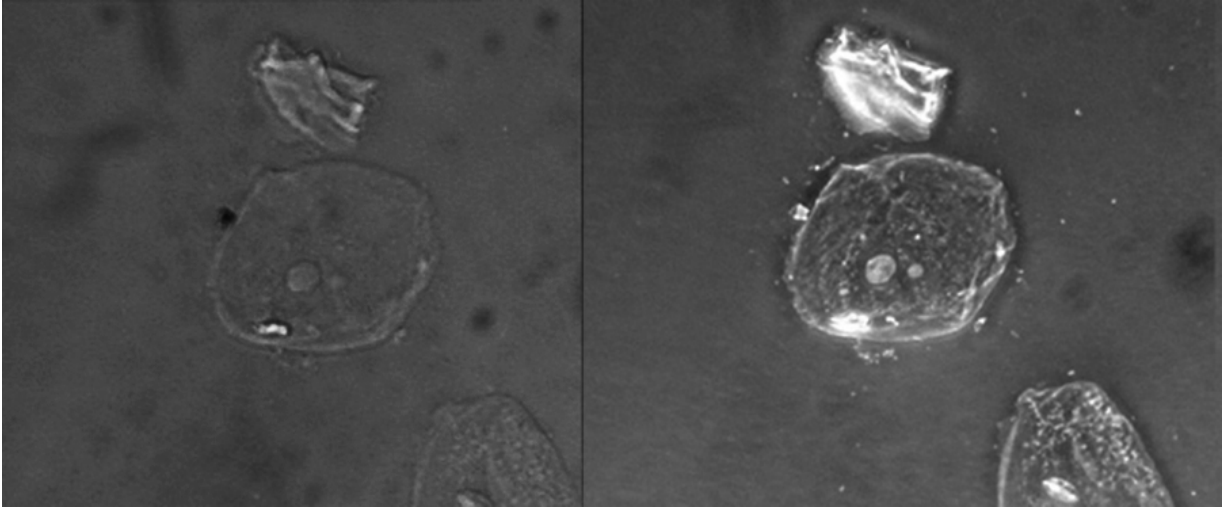
- 4 Wavelengths in phase or out of phase either add together or cancel out each other.
- 3 Light traveling directly from the condenser lens and light traveling through the specimen are out of phase when they pass through the objective and phase plates.
- 2 Object or specimen refracts or reflects light.
- 1 Annular stop in the condenser produces a cone of light focused on the specimen.

- Illuminating light
- Diffracted light
- Undiffracted light
- Combined diffracted and undiffracted light



This diagram of a phase-contrast microscope illustrates phase differences between light passing through the object and background. These differences are produced by passing the rays through different parts of a phase plate. The light rays are superimposed in the image plane, producing contrast due to their interference.

Because it increases contrast without requiring stains, phase-contrast microscopy is often used to observe live specimens. Certain structures, such as organelles in eukaryotic cells and endospores in prokaryotic cells, are especially well visualized with phase-contrast microscopy ([link](#)).



This figure compares a brightfield image (left) with a phase-contrast image (right) of the same unstained simple squamous epithelial cells. The cells are in the center and bottom right of each photograph (the irregular item above the cells is acellular debris). Notice that the unstained cells in the brightfield image are almost invisible against the background, whereas the cells in the phase-contrast image appear to glow against the background, revealing far more detail.

Differential Interference Contrast Microscopes

Differential interference contrast (DIC) microscopes (also known as Nomarski optics) are similar to phase-contrast microscopes in that they use interference patterns to enhance contrast between different features of a specimen. In a DIC microscope, two beams of light are created in which the direction of wave movement (polarization) differs. Once the beams pass through either the specimen or specimen-free space, they are recombined and effects of the specimens cause differences in the interference patterns generated by the combining of the beams. This results in high-contrast images of living organisms with a three-dimensional appearance. These microscopes are especially useful in distinguishing structures within live, unstained specimens. ([link](#))



A DIC image of *Fonsecaea pedrosoi* grown on modified Leonian's agar. This fungus causes chromoblastomycosis, a chronic skin infection common in tropical and subtropical climates.

Note:

- What are some advantages of phase-contrast and DIC microscopy?

Fluorescence Microscopes

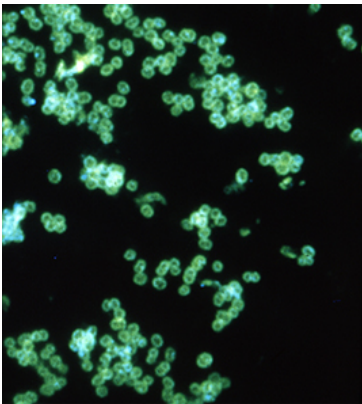
A **fluorescence microscope** uses fluorescent chromophores called **fluorochromes**, which are capable of absorbing energy from a light source and then emitting this energy as visible light. Fluorochromes include naturally fluorescent substances (such as chlorophylls) as well as fluorescent stains that are added to the specimen to create contrast. Dyes such as Texas red and FITC are examples of fluorochromes. Other examples include the nucleic acid dyes 4',6'-diamidino-2-phenylindole (DAPI) and acridine orange.

The microscope transmits an excitation light, generally a form of EMR with a short wavelength, such as ultraviolet or blue light, toward the specimen; the chromophores absorb the excitation light and emit visible light with longer wavelengths. The excitation light is then filtered out (in part because ultraviolet light is harmful to the eyes) so that only visible light passes through the ocular lens. This produces an image of the specimen in bright colors against a dark background.

Fluorescence microscopes are especially useful in clinical microbiology. They can be used to identify pathogens, to find particular species within an environment, or to find the locations of particular molecules and structures within a cell. Approaches have also been developed to distinguish living from dead cells using fluorescence microscopy based upon whether they take up particular fluorochromes. Sometimes, multiple fluorochromes are used on the same specimen to show different structures or features.

One of the most important applications of fluorescence microscopy is a technique called **immunofluorescence**, which is used to identify certain disease-causing microbes by observing whether antibodies bind to them. (Antibodies are protein molecules produced by the immune system that attach to specific pathogens to kill or inhibit them.) There are two approaches to this technique: direct immunofluorescence assay (DFA) and indirect immunofluorescence assay (IFA). In DFA, specific antibodies (e.g., those that target the rabies virus) are stained with a fluorochrome. If the specimen contains the targeted pathogen, one can observe the antibodies binding to the pathogen under the fluorescent microscope. This is called a primary antibody stain because the stained antibodies attach directly to the pathogen.

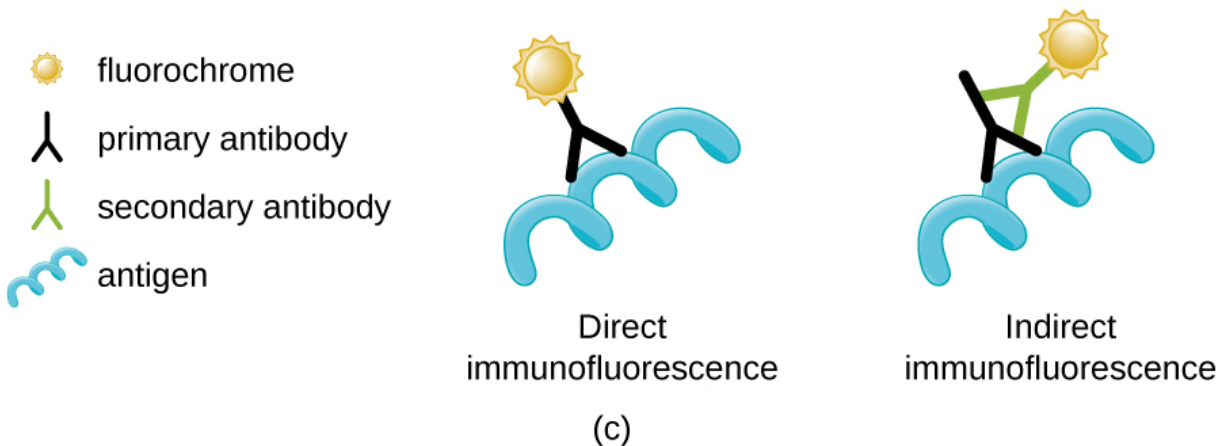
In IFA, secondary antibodies are stained with a fluorochrome rather than primary antibodies. Secondary antibodies do not attach directly to the pathogen, but they do bind to primary antibodies. When the unstained primary antibodies bind to the pathogen, the fluorescent secondary antibodies can be observed binding to the primary antibodies. Thus, the secondary antibodies are attached indirectly to the pathogen. Since multiple secondary antibodies can often attach to a primary antibody, IFA increases the number of fluorescent antibodies attached to the specimen, making it easier visualize features in the specimen ([\[link\]](#)).



(a)



(b)



(a) A direct immunofluorescent stain is used to visualize *Neisseria gonorrhoeae*, the bacterium that causes gonorrhea. (b) An indirect immunofluorescent stain is used to visualize larvae of *Schistosoma*

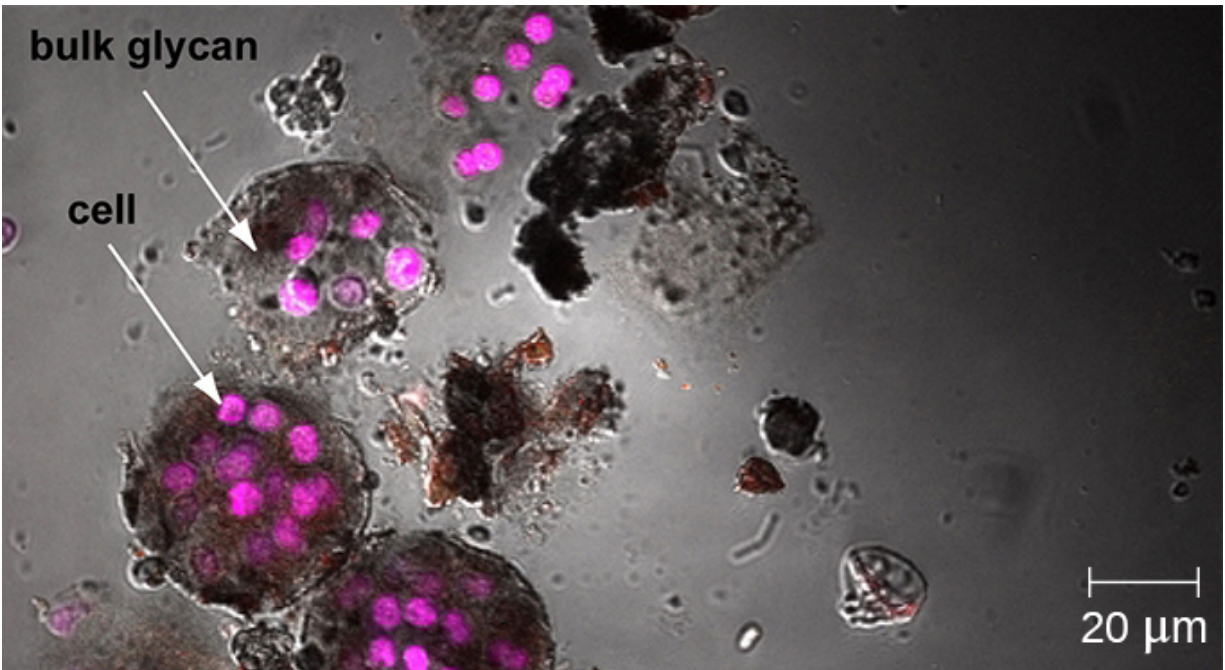
mansoni, a parasitic worm that causes schistosomiasis, an intestinal disease common in the tropics. (c) In direct immunofluorescence, the stain is absorbed by a primary antibody, which binds to the antigen. In indirect immunofluorescence, the stain is absorbed by a secondary antibody, which binds to a primary antibody, which, in turn, binds to the antigen. (credit a: modification of work by Centers for Disease Control and Prevention; credit b: modification of work by Centers for Disease Control and Prevention)

Note:

- Why must fluorochromes be used to examine a specimen under a fluorescence microscope?

Confocal Microscopes

Whereas other forms of light microscopy create an image that is maximally focused at a single distance from the observer (the depth, or z-plane), a **confocal microscope** uses a laser to scan multiple z-planes successively. This produces numerous two-dimensional, high-resolution images at various depths, which can be constructed into a three-dimensional image by a computer. As with fluorescence microscopes, fluorescent stains are generally used to increase contrast and resolution. Image clarity is further enhanced by a narrow aperture that eliminates any light that is not from the z-plane. Confocal microscopes are thus very useful for examining thick specimens such as biofilms, which can be examined alive and unfixed ([link](#)).



Confocal microscopy can be used to visualize structures such as this roof-dwelling cyanobacterium biofilm. (credit: modification of work by American Society for Microbiology)

Note:



Explore a rotating three-dimensional [view](#) of a biofilm as observed under a confocal microscope. After navigating to the webpage, click the “play” button to launch the video.

Two-Photon Microscopes

While the original fluorescent and confocal microscopes allowed better visualization of unique features in specimens, there were still problems that prevented optimum visualization. The effective sensitivity of fluorescence microscopy when viewing thick specimens was generally limited by out-of-focus flare, which resulted in poor resolution. This limitation was greatly reduced in the confocal microscope through the use of a confocal pinhole to reject out-of-focus background fluorescence with thin ($<1\text{ }\mu\text{m}$), unblurred optical sections. However, even the confocal microscopes lacked the resolution needed for viewing thick tissue samples. These problems were resolved with the development of the **two-photon microscope**, which uses a scanning technique, fluorochromes, and long-wavelength light (such as infrared) to visualize specimens. The low energy associated with the long-wavelength light means that two photons must strike a location at the same time to excite the fluorochrome. The low energy of the excitation light is less damaging to cells, and the long wavelength of the excitation light more easily penetrates deep into thick specimens. This makes the two-photon microscope useful for examining living cells within intact tissues—brain slices, embryos, whole organs, and even entire animals.

Currently, use of two-photon microscopes is limited to advanced clinical and research laboratories because of the high costs of the instruments. A single two-photon microscope typically costs between \$300,000 and \$500,000, and the lasers used to excite the dyes used on specimens are also very expensive. However, as technology improves, two-photon microscopes may become more readily available in clinical settings.

Note:

- What types of specimens are best examined using confocal or two-photon microscopy?

Electron Microscopy

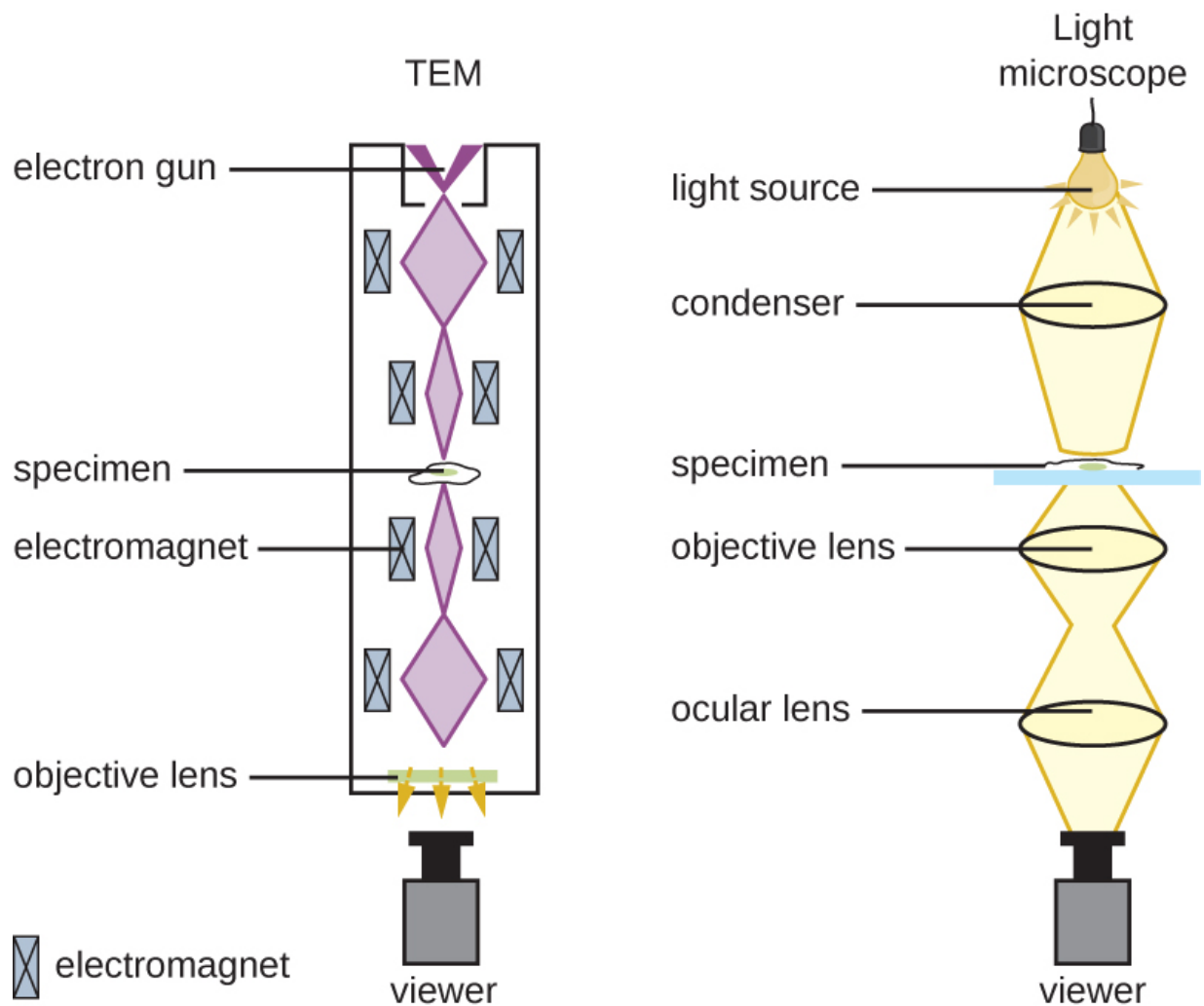
The maximum theoretical resolution of images created by light microscopes is ultimately limited by the wavelengths of visible light. Most light microscopes can only magnify 1000×, and a few can magnify up to 1500×, but this does not begin to approach the magnifying power of an **electron microscope (EM)**, which uses short-wavelength electron beams rather than light to increase magnification and resolution.

Electrons, like electromagnetic radiation, can behave as waves, but with wavelengths of 0.005 nm, they can produce much better resolution than visible light. An EM can produce a sharp image that is magnified up to 100,000×. Thus, EMs can resolve subcellular structures as well as some molecular structures (e.g., single strands of DNA); however, electron microscopy cannot be used on living material because of the methods needed to prepare the specimens.

There are two basic types of EM: the **transmission electron microscope (TEM)** and the **scanning electron microscope (SEM)** ([\[link\]](#)). The TEM is somewhat analogous to the brightfield light microscope in terms of the way it functions. However, it uses an electron beam from above the specimen that is focused using a magnetic lens (rather than a glass lens) and projected through the specimen onto a detector. Electrons pass through the specimen, and then the detector captures the image ([\[link\]](#)).



A transmission electron microscope (TEM).

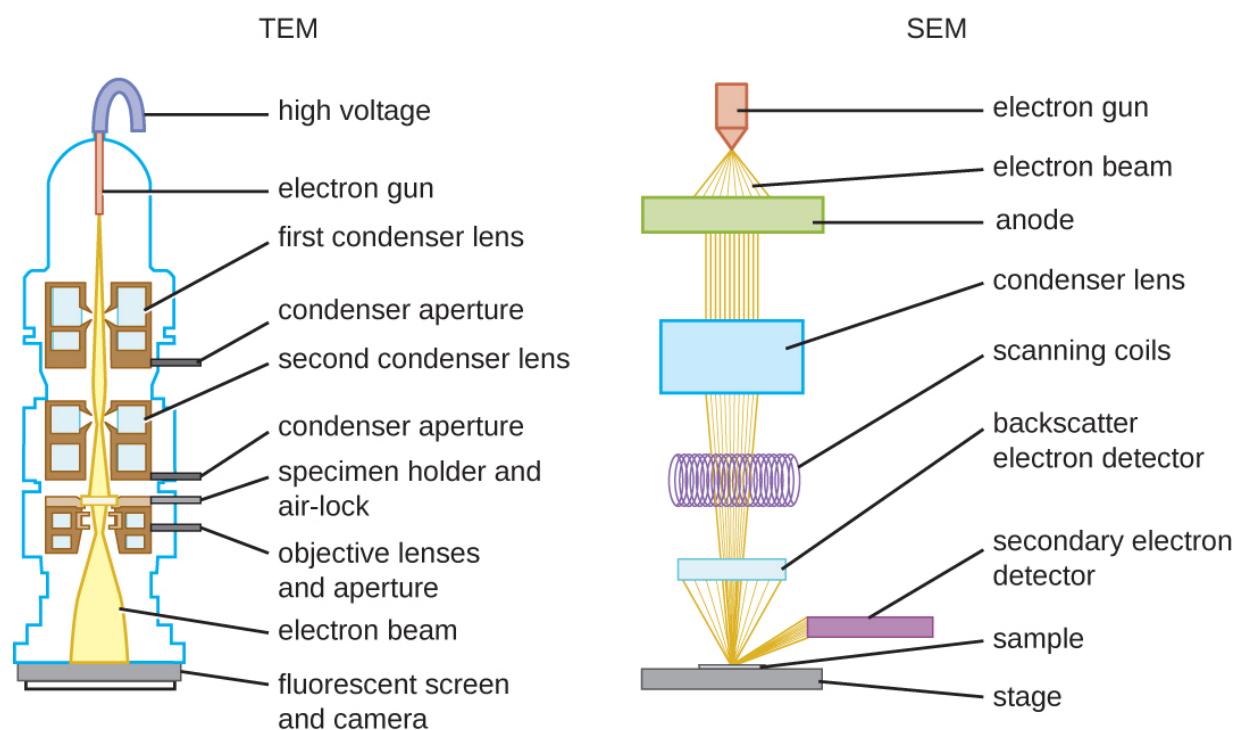


Electron microscopes use magnets to focus electron beams similarly to the way that light microscopes use lenses to focus light.

For electrons to pass through the specimen in a TEM, the specimen must be extremely thin (20–100 nm thick). The image is produced because of varying opacity in various parts of the specimen. This opacity can be enhanced by staining the specimen with materials such as heavy metals, which are electron dense. TEM requires that the beam and specimen be in a vacuum and that the specimen be very thin and dehydrated. The specific steps needed to prepare a specimen for observation under an EM are discussed in detail in the next section.

SEMs form images of surfaces of specimens, usually from electrons that are knocked off of specimens by a beam of electrons. This can create highly detailed images with a three-dimensional appearance that are displayed on a monitor ([link]). Typically, specimens are dried and prepared with fixatives that reduce artifacts, such as shriveling, that can be produced by drying, before being sputter-coated with a thin layer of metal such as gold. Whereas transmission electron microscopy requires very thin sections and allows one to see internal structures such as organelles and the interior of membranes, scanning electron microscopy can be used to view the surfaces of larger objects (such as a pollen grain) as well as the surfaces of very small samples ([link]). Some EMs can magnify an image up to 2,000,000 $\times$. [footnote]

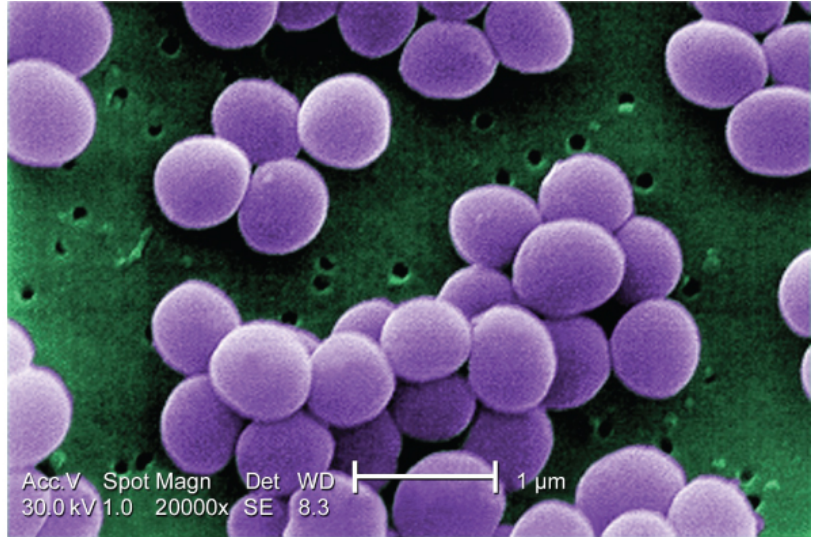
“JEM-ARM200F Transmission Electron Microscope,” *JEOL USA Inc*, <http://www.jeolusa.com/PRODUCTS/TransmissionElectronMicroscopes%28TEM%29/200kV/JEM-ARM200F/tabid/663/Default.aspx#195028-specifications>. Accessed 8/28/2015.



These schematic illustrations compare the components of transmission electron microscopes and scanning electron microscopes.



(a)



(b)

(a) This TEM image of cells in a biofilm shows well-defined internal structures of the cells because of varying levels of opacity in the specimen. (b) This color-enhanced SEM image of the bacterium *Staphylococcus aureus* illustrates the ability of scanning electron microscopy to render three-dimensional images of the surface structure of cells. (credit a: modification of work by American Society for Microbiology; credit b: modification of work by Centers for Disease Control and Prevention)

Note:

- What are some advantages and disadvantages of electron microscopy, as opposed to light microscopy, for examining microbiological specimens?

- What kinds of specimens are best examined using TEM? SEM?

Note:

Using Microscopy to Study Biofilms

A biofilm is a complex community of one or more microorganism species, typically forming as a slimy coating attached to a surface because of the production of an extrapolymeric substance (EPS) that attaches to a surface or at the interface between surfaces (e.g., between air and water). In nature, biofilms are abundant and frequently occupy complex niches within ecosystems ([\[link\]](#)). In medicine, biofilms can coat medical devices and exist within the body. Because they possess unique characteristics, such as increased resistance against the immune system and to antimicrobial drugs, biofilms are of particular interest to microbiologists and clinicians alike. Because biofilms are thick, they cannot be observed very well using light microscopy; slicing a biofilm to create a thinner specimen might kill or disturb the microbial community. Confocal microscopy provides clearer images of biofilms because it can focus on one z-plane at a time and produce a three-dimensional image of a thick specimen. Fluorescent dyes can be helpful in identifying cells within the matrix. Additionally, techniques such as immunofluorescence and fluorescence in situ hybridization (FISH), in which fluorescent probes are used to bind to DNA, can be used.

Electron microscopy can be used to observe biofilms, but only after dehydrating the specimen, which produces undesirable artifacts and distorts the specimen. In addition to these approaches, it is possible to follow water currents through the shapes (such as cones and mushrooms) of biofilms, using video of the movement of fluorescently coated beads ([\[link\]](#)).

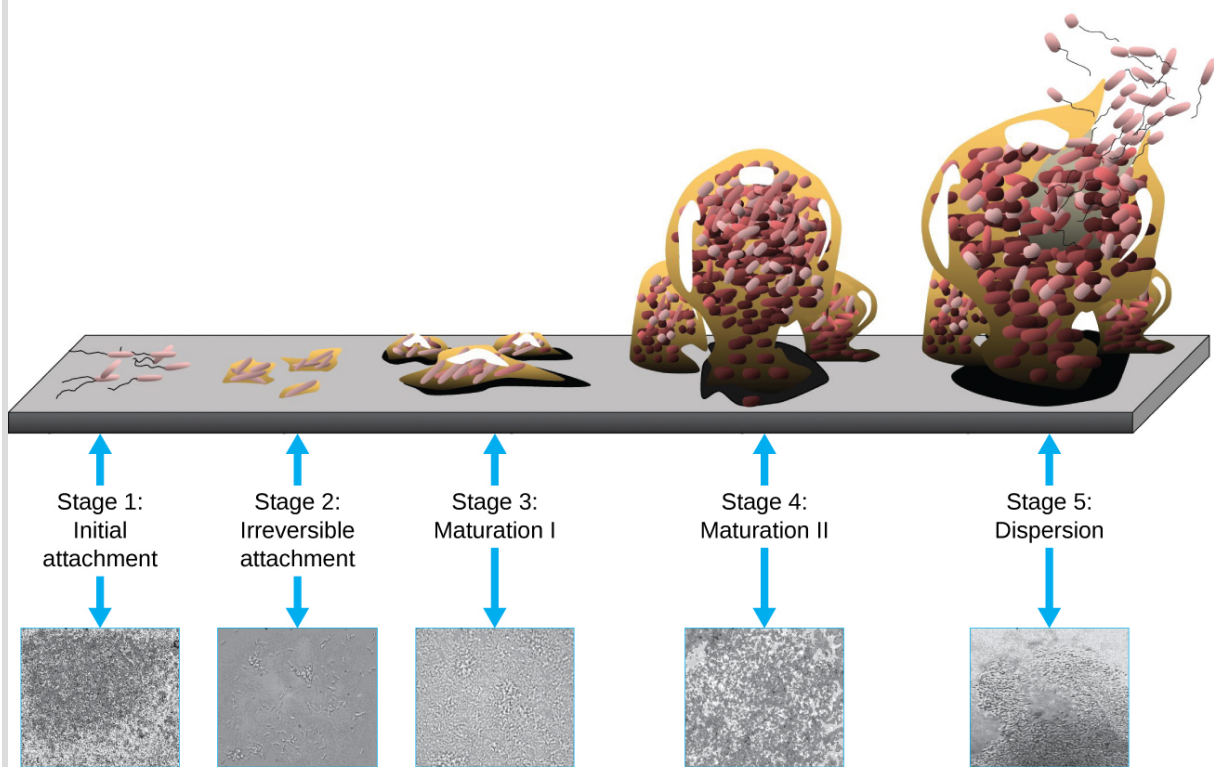
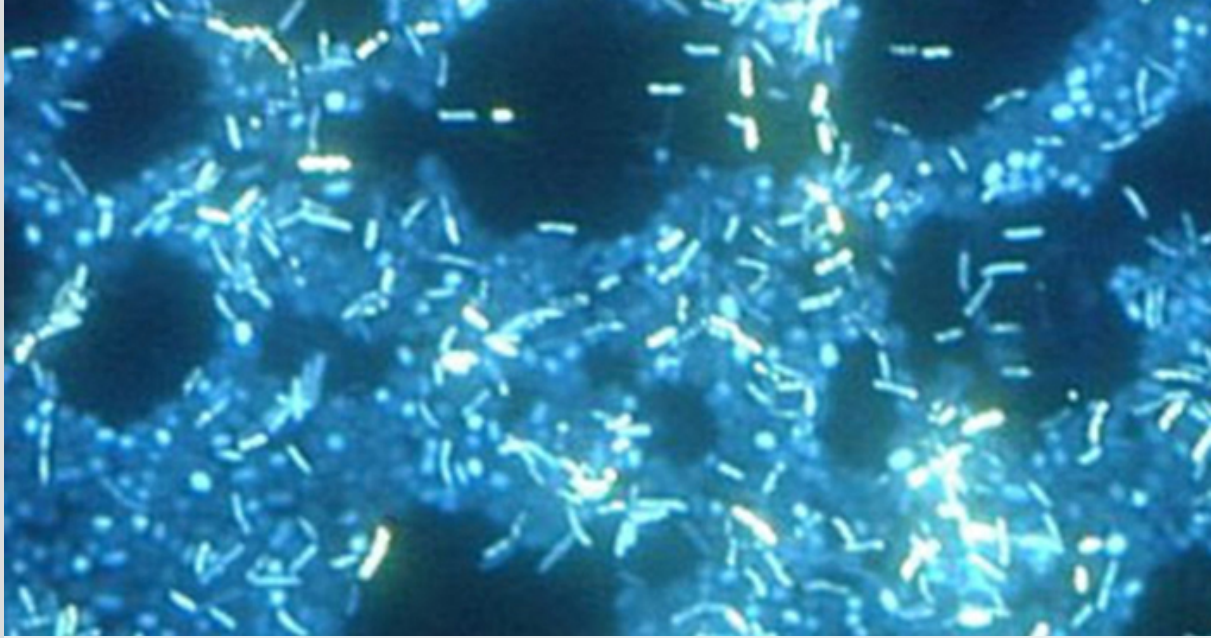


Diagram showing five stages of biofilm development of *Pseudomonas aeruginosa*. All photomicrographs are shown to same scale.

A biofilm forms when planktonic (free-floating) bacteria of one or more species adhere to a surface, produce slime, and form a colony.
(credit: Public Library of Science)



In this image, multiple species of bacteria grow in a biofilm on stainless steel (stained with DAPI for epifluorescence microscopy).
(credit: Ricardo Murga, Rodney Donlan)

Scanning Probe Microscopy

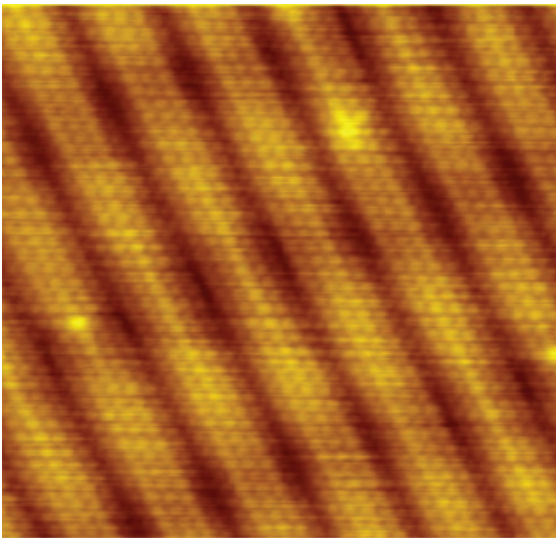
A **scanning probe microscope** does not use light or electrons, but rather very sharp probes that are passed over the surface of the specimen and interact with it directly. This produces information that can be assembled into images with magnifications up to $100,000,000\times$. Such large magnifications can be used to observe individual atoms on surfaces. To date, these techniques have been used primarily for research rather than for diagnostics.

There are two types of scanning probe microscope: the **scanning tunneling microscope (STM)** and the **atomic force microscope (AFM)**. An STM uses a probe that is passed just above the specimen as a constant voltage bias creates the potential for an electric current between the probe and the

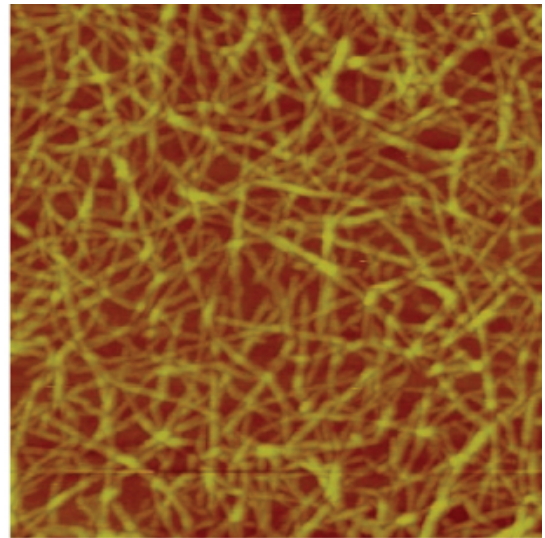
specimen. This current occurs via quantum tunneling of electrons between the probe and the specimen, and the intensity of the current is dependent upon the distance between the probe and the specimen. The probe is moved horizontally above the surface and the intensity of the current is measured. Scanning tunneling microscopy can effectively map the structure of surfaces at a resolution at which individual atoms can be detected.

Similar to an STM, AFMs have a thin probe that is passed just above the specimen. However, rather than measuring variations in the current at a constant height above the specimen, an AFM establishes a constant current and measures variations in the height of the probe tip as it passes over the specimen. As the probe tip is passed over the specimen, forces between the atoms (van der Waals forces, capillary forces, chemical bonding, electrostatic forces, and others) cause it to move up and down. Deflection of the probe tip is determined and measured using Hooke's law of elasticity, and this information is used to construct images of the surface of the specimen with resolution at the atomic level ([\[link\]](#)).

[\[link\]](#), [\[link\]](#), and [\[link\]](#) summarize the microscopy techniques for light microscopes, electron microscopes, and scanning probe microscopes, respectively.



(a)

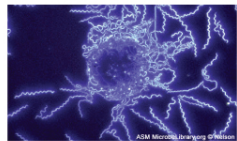
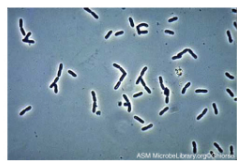
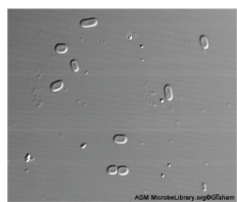
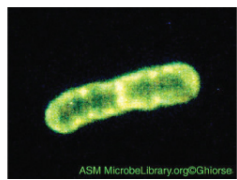
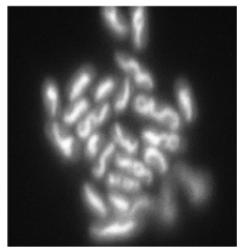
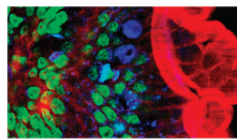


(b)

STMs and AFMs allow us to view images at the atomic level. (a) This STM image of a pure gold surface shows individual atoms of gold arranged in columns. (b) This AFM image shows long, strand-like molecules of nanocellulose, a laboratory-created substance derived from plant fibers. (credit a: modification of work by “Erwinrossen”/Wikimedia Commons)

Note:

- Which has higher magnification, a light microscope or a scanning probe microscope?
- Name one advantage and one limitation of scanning probe microscopy.

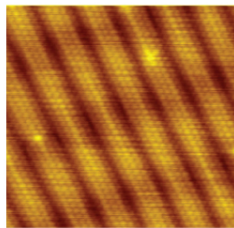
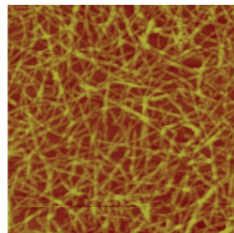
LIGHT MICROSCOPES Magnification: up to about 1000× Use visible or ultraviolet light to produce an image.		
Microscope Type	Key Uses	Sample Images
Brightfield	Commonly used in a wide variety of laboratory applications as the standard microscope; produces an image on a bright background. Example: <i>Bacillus</i> sp. showing endospores.	
Darkfield	Increases contrast without staining by producing a bright image on a darker background; especially useful for viewing live specimens. Example: <i>Borrelia burgdorferi</i>	
Phase contrast	Uses refraction and interference caused by structures in the specimen to create high-contrast, high-resolution images without staining, making it useful for viewing live specimens, and structures such as endospores and organelles. Example: <i>Pseudomonas</i> sp.	
Differential interference contrast (DIC)	Uses interference patterns to enhance contrast between different features of a specimen to produce high-contrast images of living organisms with a three-dimensional appearance, making it especially useful in distinguishing structures within live, unstained specimens; images viewed reveal detailed structures within cells. Example: <i>Escherichia coli</i> O157:H7	
Fluorescence	Uses fluorescent stains to produce an image; can be used to identify pathogens, to find particular species, to distinguish living from dead cells, or to find locations of particular molecules within a cell; also used for immunofluorescence. Example: <i>P. putida</i> stained with fluorescent dyes to visualize the capsule.	
Confocal	Uses a laser to scan multiple z-planes successively, producing numerous two-dimensional, high-resolution images at various depths that can be constructed into a three-dimensional image by a computer, making this useful for examining thick specimens such as biofilms. Example: <i>Escherichia coli</i> stained with acridine orange dye to show the nucleoid regions of the cells.	
Two-photon	Uses a scanning technique, fluorochromes, and long-wavelength light (such as infrared) to penetrate deep into thick specimens such as biofilms. Example: Mouse intestine cells stained with fluorescent dye.	

(credit “Brightfield”: modification of work by American Society for Microbiology; credit “Darkfield”: modification of work by American Society for Microbiology; credit “Phase contrast”: modification of work by American Society for Microbiology; credit “DIC”:

modification of work by American Society for Microbiology; credit “Fluorescence”: modification of work by American Society for Microbiology; credit “Confocal”: modification of work by American Society for Microbiology; credit “Two-photon”: modification of work by Alberto Diaspro, Paolo Bianchini, Giuseppe Vicidomini, Mario Faretta, Paola Ramoino, Cesare Usai)

ELECTRON MICROSCOPES Magnification: 20–100,000× or more Use electron beams focused with magnets to produce an image.		
Microscope Type	Key Uses	Sample Images
Transmission (TEM)	Uses electron beams that pass through a specimen to visualize small images; useful to observe small, thin specimens such as tissue sections and subcellular structures. Example: <i>Ebola virus</i>	
Scanning (SEM)	Uses electron beams to visualize surfaces; useful to observe the three-dimensional surface details of specimens. Example: <i>Campylobacter jejuni</i>	

(credit “TEM”: modification of work by American Society for Microbiology; credit “SEM”: modification of work by American Society for Microbiology)

SCANNING PROBE MICROSCOPES Magnification: 100–100,000,000× or more Use very short probes that are passed over the surface of the specimen and interact with it directly.		
Microscope Type	Key Uses	Sample Images
<i>Scanning tunneling (STM)</i>	Uses a probe passed horizontally at a constant distance just above the specimen while the intensity of the current is measured; can map the structure of surfaces at the atomic level; works best on conducting materials but can also be used to examine organic materials such as DNA, if fixed on a surface. Example: Image of surface reconstruction on a clean gold [Au(100)] surface, as visualized using scanning tunneling microscopy.	
<i>Atomic force (AFM)</i>	Can be used in several ways, including using a laser focused on a cantilever to measure the bending of the tip or a probe passed above the specimen while the height needed to maintain a constant current is measured; useful to observe specimens at the atomic level and can be more easily used with nonconducting samples. Example: AFM height image of carboxymethylated nanocellulose adsorbed on a silica surface.	

Key Concepts and Summary

- Numerous types of microscopes use various technologies to generate micrographs. Most are useful for a particular type of specimen or application.
- **Light microscopy** uses lenses to focus light on a specimen to produce an image. Commonly used light microscopes include **brightfield**, **darkfield**, **phase-contrast**, **differential interference contrast**, **fluorescence**, **confocal**, and **two-photon** microscopes.
- **Electron microscopy** focuses electrons on the specimen using magnets, producing much greater magnification than light microscopy. The **transmission electron microscope (TEM)** and **scanning electron microscope (SEM)** are two common forms.
- **Scanning probe microscopy** produces images of even greater magnification by measuring feedback from sharp probes that interact with the specimen. Probe microscopes include the **scanning tunneling microscope (STM)** and the **atomic force microscope (AFM)**.

Multiple Choice

Exercise:

Problem:

Which would be the best choice for viewing internal structures of a living protist such as a *Paramecium*?

- a. a brightfield microscope with a stain
- b. a brightfield microscope without a stain
- c. a darkfield microscope
- d. a transmission electron microscope

Solution:

C

Exercise:

Problem:

Which type of microscope is especially useful for viewing thick structures such as biofilms?

- a. a transmission electron microscope
- b. a scanning electron microscopes
- c. a phase-contrast microscope
- d. a confocal scanning laser microscope
- e. an atomic force microscope

Solution:

D

Exercise:

Problem:

Which type of microscope would be the best choice for viewing very small surface structures of a cell?

- a. a transmission electron microscope
 - b. a scanning electron microscope
 - c. a brightfield microscope
 - d. a darkfield microscope
 - e. a phase-contrast microscope
-

Solution:

B

Exercise:

Problem: What type of microscope uses an annular stop?

- a. a transmission electron microscope
 - b. a scanning electron microscope
 - c. a brightfield microscope
 - d. a darkfield microscope
 - e. a phase-contrast microscope
-

Solution:

E

Exercise:

Problem:

What type of microscope uses a cone of light so that light only hits the specimen indirectly, producing a darker image on a brighter background?

- a. a transmission electron microscope
- b. a scanning electron microscope
- c. a brightfield microscope
- d. a darkfield microscope
- e. a phase-contrast microscope

Solution:

D

Fill in the Blank

Exercise:

Problem:

Chromophores that absorb and then emit light are called _____.

Solution:

fluorochromes

Exercise:

Problem:

In a(n) _____ microscope, a probe located just above the specimen moves up and down in response to forces between the atoms and the tip of the probe.

Solution:

atomic force microscope

Exercise:

Problem:

What is the total magnification of a specimen that is being viewed with a standard ocular lens and a 40× objective lens?

Solution:

400×

Short Answer

Exercise:

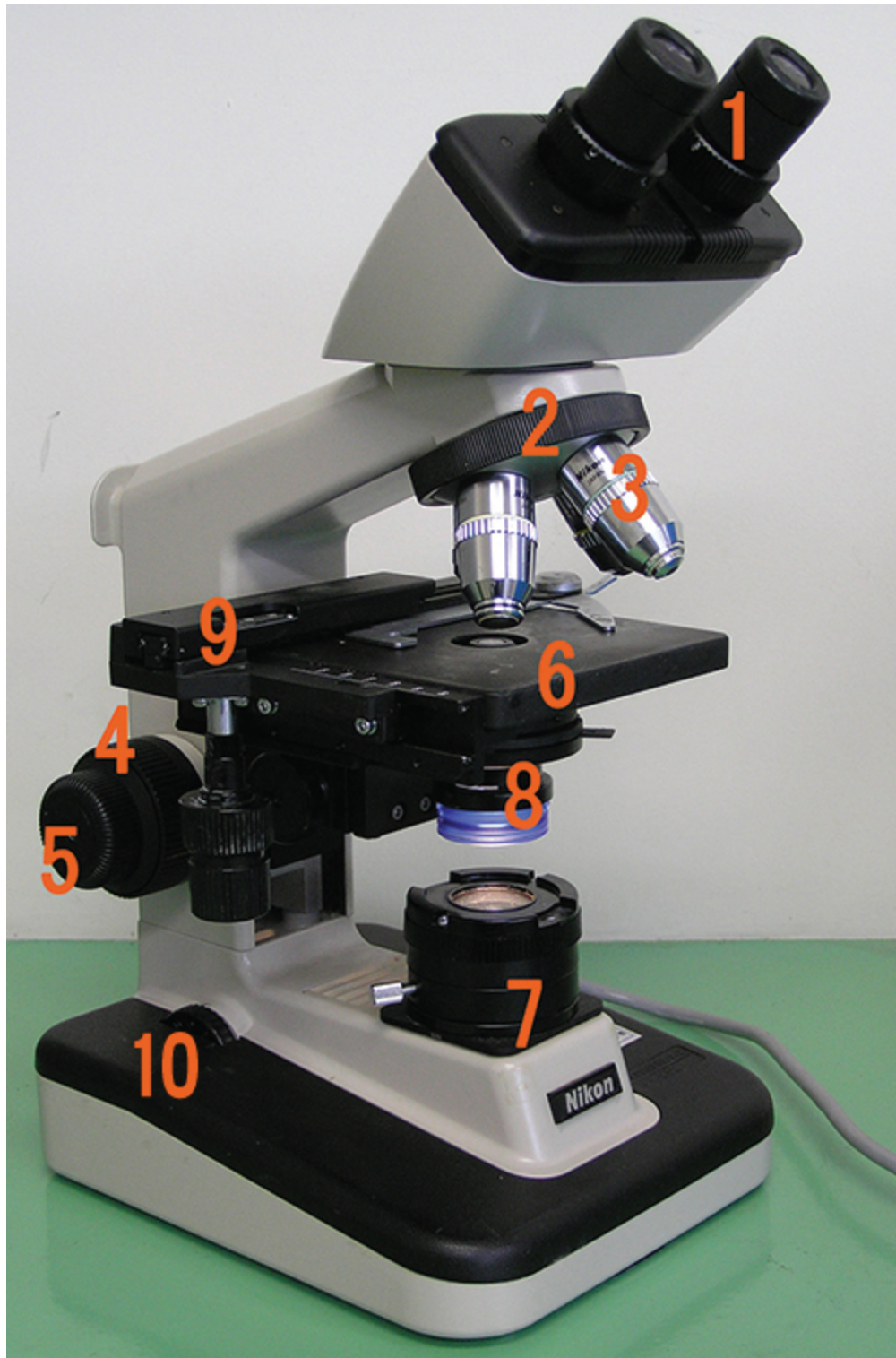
Problem:

What is the function of the condenser in a brightfield microscope?

Art Connection

Exercise:

Problem: Label each component of the brightfield microscope.



Critical Thinking

Exercise:**Problem:**

When focusing a light microscope, why is it best to adjust the focus using the coarse focusing knob before using the fine focusing knob?

Exercise:**Problem:**

You need to identify structures within a cell using a microscope. However, the image appears very blurry even though you have a high magnification. What are some things that you could try to improve the resolution of the image? Describe the most basic factors that affect resolution when you first put the slide onto the stage; then consider more specific factors that could affect resolution for 40× and 100× lenses.

Staining Microscopic Specimens

LEARNING OBJECTIVES

- Differentiate between simple and differential stains
- Describe the unique features of commonly used stains
- Explain the procedures and name clinical applications for Gram, endospore, acid-fast, negative capsule, and flagella staining

In their natural state, most of the cells and microorganisms that we observe under the microscope lack color and contrast. This makes it difficult, if not impossible, to detect important cellular structures and their distinguishing characteristics without artificially treating specimens. We have already alluded to certain techniques involving stains and fluorescent dyes, and in this section we will discuss specific techniques for sample preparation in greater detail. Indeed, numerous methods have been developed to identify specific microbes, cellular structures, DNA sequences, or indicators of infection in tissue samples, under the microscope. Here, we will focus on the most clinically relevant techniques.

Preparing Specimens for Light Microscopy

In clinical settings, light microscopes are the most commonly used microscopes. There are two basic types of preparation used to view specimens with a light microscope: wet mounts and fixed specimens.

The simplest type of preparation is the **wet mount**, in which the specimen is placed on the slide in a drop of liquid. Some specimens, such as a drop of

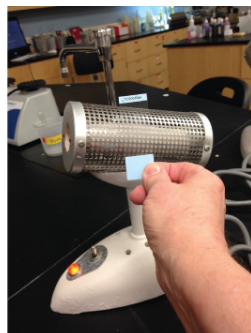
urine, are already in a liquid form and can be deposited on the slide using a dropper. Solid specimens, such as a skin scraping, can be placed on the slide before adding a drop of liquid to prepare the wet mount. Sometimes the liquid used is simply water, but often stains are added to enhance contrast. Once the liquid has been added to the slide, a coverslip is placed on top and the specimen is ready for examination under the microscope.

The second method of preparing specimens for light microscopy is **fixation**. The “fixing” of a sample refers to the process of attaching cells to a slide. Fixation is often achieved either by heating (heat fixing) or chemically treating the specimen. In addition to attaching the specimen to the slide, fixation also kills microorganisms in the specimen, stopping their movement and metabolism while preserving the integrity of their cellular components for observation.

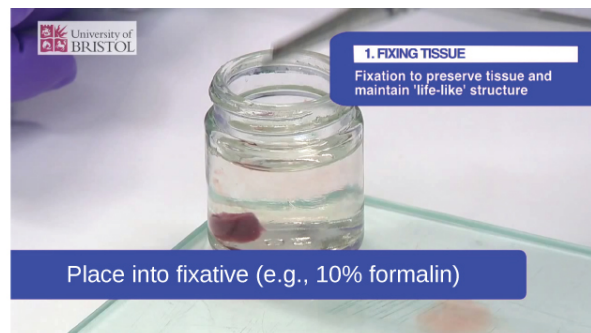
To heat-fix a sample, a thin layer of the specimen is spread on the slide (called a **smear**), and the slide is then briefly heated over a heat source ([\[link\]](#)). Chemical fixatives are often preferable to heat for tissue specimens. Chemical agents such as acetic acid, ethanol, methanol, formaldehyde (formalin), and glutaraldehyde can denature proteins, stop biochemical reactions, and stabilize cell structures in tissue samples ([\[link\]](#)).



(a)



(b)



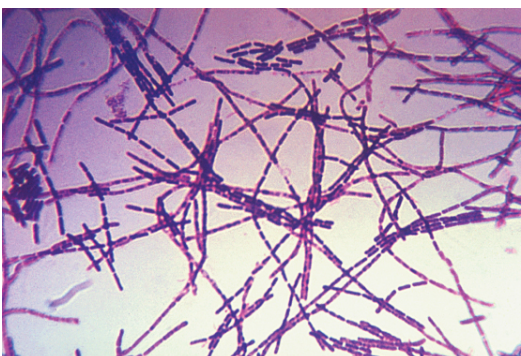
(c)

- (a) A specimen can be heat-fixed by using a slide warmer like this one. (b) Another method for heat-fixing a specimen is to hold a slide with a smear over a microincinerator. (c) This tissue sample is being fixed in a solution of formalin (also known as formaldehyde). Chemical

fixation kills microorganisms in the specimen, stopping degradation of the tissues and preserving their structure so that they can be examined later under the microscope. (credit a: modification of work by Nina Parker; credit b: modification of work by Nina Parker; credit c: modification of work by “University of Bristol”/YouTube)

In addition to fixation, **staining** is almost always applied to color certain features of a specimen before examining it under a light microscope. Stains, or dyes, contain salts made up of a positive ion and a negative ion. Depending on the type of dye, the positive or the negative ion may be the chromophore (the colored ion); the other, uncolored ion is called the counterion. If the chromophore is the positively charged ion, the stain is classified as a **basic dye**; if the negative ion is the chromophore, the stain is considered an **acidic dye**.

Dyes are selected for staining based on the chemical properties of the dye and the specimen being observed, which determine how the dye will interact with the specimen. In most cases, it is preferable to use a **positive stain**, a dye that will be absorbed by the cells or organisms being observed, adding color to objects of interest to make them stand out against the background. However, there are scenarios in which it is advantageous to use a **negative stain**, which is absorbed by the background but not by the cells or organisms in the specimen. Negative staining produces an outline or silhouette of the organisms against a colorful background ([\[link\]](#)).



(a)



(b)



(c)

(a) These *Bacillus anthracis* cells have absorbed crystal violet, a basic positive stain. (b) This specimen of *Spinoloricus*, a microscopic marine organism, has been stained with rose bengal, a positive acidic stain. (c) These *B. megaterium* appear to be white because they have not absorbed the negative red stain applied to the slide. (credit a: modification of work by Centers for Disease Control and Prevention; credit b: modification of work by Roberto Danovaro, Antonio Pusceddu, Cristina Gambi, Iben Heiner, Reinhardt Mobjerg Kristensen; credit c: modification of work by Anh-Hue Tu)

Because cells typically have negatively charged cell walls, the positive chromophores in basic dyes tend to stick to the cell walls, making them positive stains. Thus, commonly used basic dyes such as basic fuchsin, crystal violet, malachite green, methylene blue, and safranin typically serve as positive stains. On the other hand, the negatively charged chromophores in acidic dyes are repelled by negatively charged cell walls, making them negative stains. Commonly used acidic dyes include acid fuchsin, eosin, and rose bengal. [\[link\]](#) provides more detail.

Some staining techniques involve the application of only one dye to the sample; others require more than one dye. In **simple staining**, a single dye is used to emphasize particular structures in the specimen. A simple stain will generally make all of the organisms in a sample appear to be the same color, even if the sample contains more than one type of organism. In contrast, **differential staining** distinguishes organisms based on their interactions with multiple stains. In other words, two organisms in a differentially stained sample may appear to be different colors. Differential staining techniques commonly used in clinical settings include Gram staining, acid-fast staining, endospore staining, flagella staining, and capsule staining. [\[link\]](#) provides more detail on these differential staining techniques.

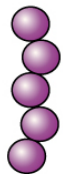
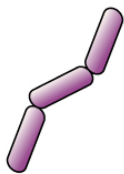
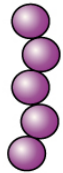
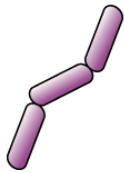
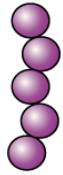
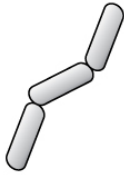
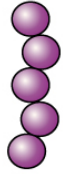
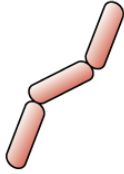
Note:

- Explain why it is important to fix a specimen before viewing it under a light microscope.
- What types of specimens should be chemically fixed as opposed to heat-fixed?
- Why might an acidic dye react differently with a given specimen than a basic dye?
- Explain the difference between a positive stain and a negative stain.
- Explain the difference between simple and differential staining.

Gram Staining

The **Gram stain procedure** is a differential staining procedure that involves multiple steps. It was developed by Danish microbiologist Hans Christian Gram in 1884 as an effective method to distinguish between bacteria with different types of cell walls, and even today it remains one of the most frequently used staining techniques. The steps of the Gram stain procedure are listed below and illustrated in [\[link\]](#).

1. First, crystal violet, a **primary stain**, is applied to a heat-fixed smear, giving all of the cells a purple color.
2. Next, Gram's iodine, a **mordant**, is added. A mordant is a substance used to set or stabilize stains or dyes; in this case, Gram's iodine acts like a trapping agent that complexes with the crystal violet, making the crystal violet–iodine complex clump and stay contained in thick layers of peptidoglycan in the cell walls.
3. Next, a **decolorizing agent** is added, usually ethanol or an acetone/ethanol solution. Cells that have thick peptidoglycan layers in their cell walls are much less affected by the decolorizing agent; they generally retain the crystal violet dye and remain purple. However, the decolorizing agent more easily washes the dye out of cells with thinner peptidoglycan layers, making them again colorless.
4. Finally, a secondary **counterstain**, usually safranin, is added. This stains the decolorized cells pink and is less noticeable in the cells that still contain the crystal violet dye.

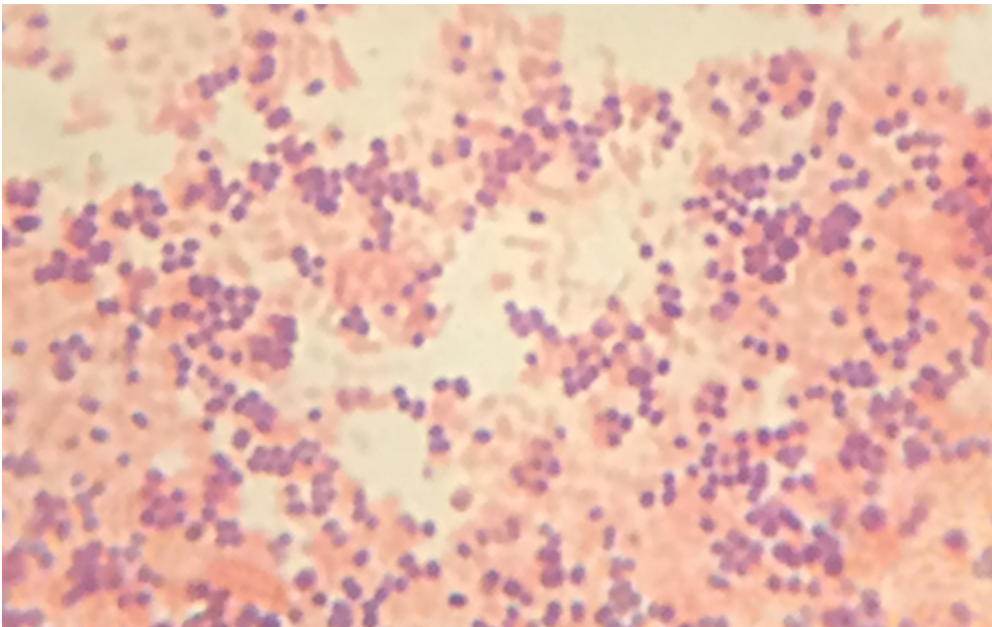
Gram stain process			
Gram staining steps	Cell effects	Gram-positive	Gram-negative
Step 1 Crystal violet <i>primary stain added to specimen smear.</i>	Stains cells purple or blue.		
Step 2 Iodine <i>mordant makes dye less soluble so it adheres to cell walls.</i>	Cells remain purple or blue.		
Step 3 Alcohol <i>decolorizer washes away stain from gram-negative cell walls.</i>	Gram-positive cells remain purple or blue. Gram-negative cells are colorless.		
Step 4 Safranin <i>counterstain allows dye adherence to gram-negative cells.</i>	Gram-positive cells remain purple or blue. Gram-negative cells appear pink or red.		

Gram-staining is a differential staining technique that uses a primary stain and a secondary counterstain to distinguish between gram-positive and gram-negative bacteria.

The purple, crystal-violet stained cells are referred to as gram-positive cells, while the red, safranin-dyed cells are gram-negative ([link](#)). However, there are several important considerations in interpreting the results of a Gram stain. First, older bacterial cells may have damage to their cell walls that causes them to appear gram-negative even if the species is gram-positive. Thus, it is best to use fresh bacterial cultures for Gram staining. Second, errors such as leaving on decolorizer too long can affect the results. In some cases, most cells will appear gram-positive while a few appear gram-negative (as in [link](#)). This suggests damage to the individual cells or

that decolorizer was left on for too long; the cells should still be classified as gram-positive if they are all the same species rather than a mixed culture.

Besides their differing interactions with dyes and decolorizing agents, the chemical differences between gram-positive and gram-negative cells have other implications with clinical relevance. For example, Gram staining can help clinicians classify bacterial pathogens in a sample into categories associated with specific properties. Gram-negative bacteria tend to be more resistant to certain antibiotics than gram-positive bacteria. We will discuss this and other applications of Gram staining in more detail in later chapters.



In this specimen, the gram-positive bacterium *Staphylococcus aureus* retains crystal violet dye even after the decolorizing agent is added. Gram-negative *Escherichia coli*, the most common Gram stain quality-control bacterium, is decolorized, and is only visible after the addition of the pink counterstain safranin.
(credit: modification of work by Nina Parker)

Note:

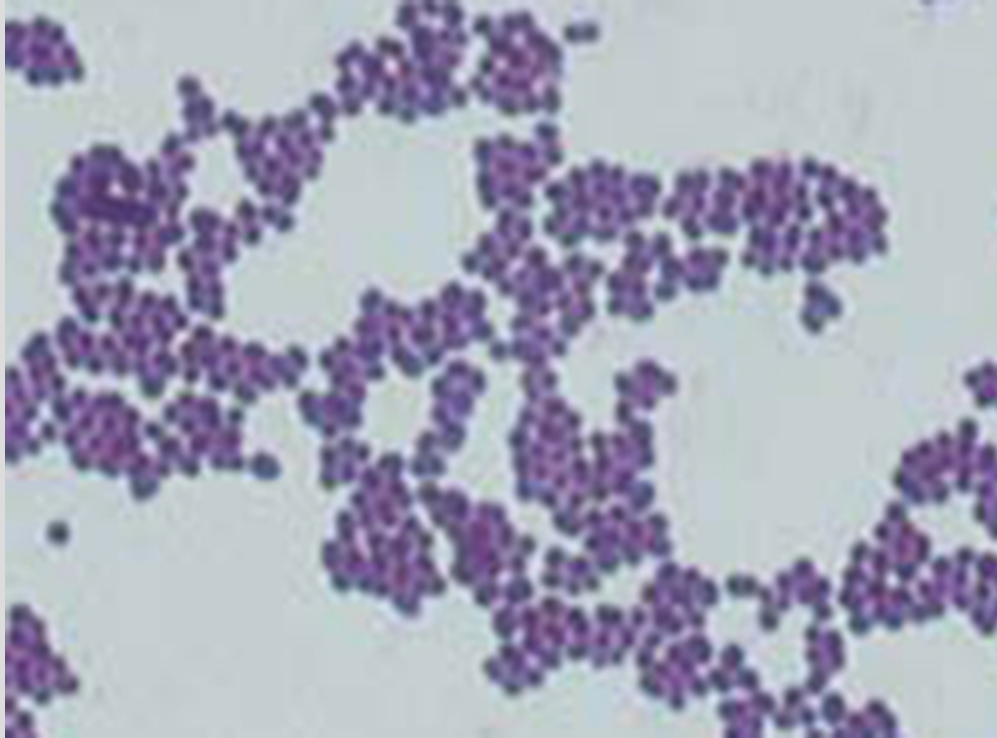
- Explain the role of Gram's iodine in the Gram stain procedure.
- Explain the role of alcohol in the Gram stain procedure.
- What color are gram-positive and gram-negative cells, respectively, after the Gram stain procedure?

Note:**Part 3**

Viewing Cindy's specimen under the darkfield microscope has provided the technician with some important clues about the identity of the microbe causing her infection. However, more information is needed to make a conclusive diagnosis. The technician decides to make a Gram stain of the specimen. This technique is commonly used as an early step in identifying pathogenic bacteria. After completing the Gram stain procedure, the technician views the slide under the brightfield microscope and sees purple, grape-like clusters of spherical cells ([link](#)).

- Are these bacteria gram-positive or gram-negative?
- What does this reveal about their cell walls?

Jump to the [next](#) Clinical Focus box. Go back to the [previous](#) Clinical Focus box.



(credit: modification of work by American Society for Microbiology)

Acid-Fast Stains

Acid-fast staining is another commonly used, differential staining technique that can be an important diagnostic tool. An **acid-fast stain** is able to differentiate two types of gram-positive cells: those that have waxy mycolic acids in their cell walls, and those that do not. Two different methods for acid-fast staining are the **Ziehl-Neelsen technique** and the **Kinyoun technique**. Both use carbolfuchsin as the primary stain. The waxy, acid-fast cells retain the carbolfuchsin even after a decolorizing agent (an acid-alcohol solution) is applied. A secondary counterstain, methylene blue, is then applied, which renders non-acid-fast cells blue.

The fundamental difference between the two carbolfuchsin-based methods is whether heat is used during the primary staining process. The Ziehl-Neelsen method uses heat to infuse the carbolfuchsin into the acid-fast cells, whereas the Kinyoun method does not use heat. Both techniques are important diagnostic tools because a number of specific diseases are caused by acid-fast bacteria (AFB). If AFB are present in a tissue sample, their red or pink color can be seen clearly against the blue background of the surrounding tissue cells ([\[link\]](#)).

Note:

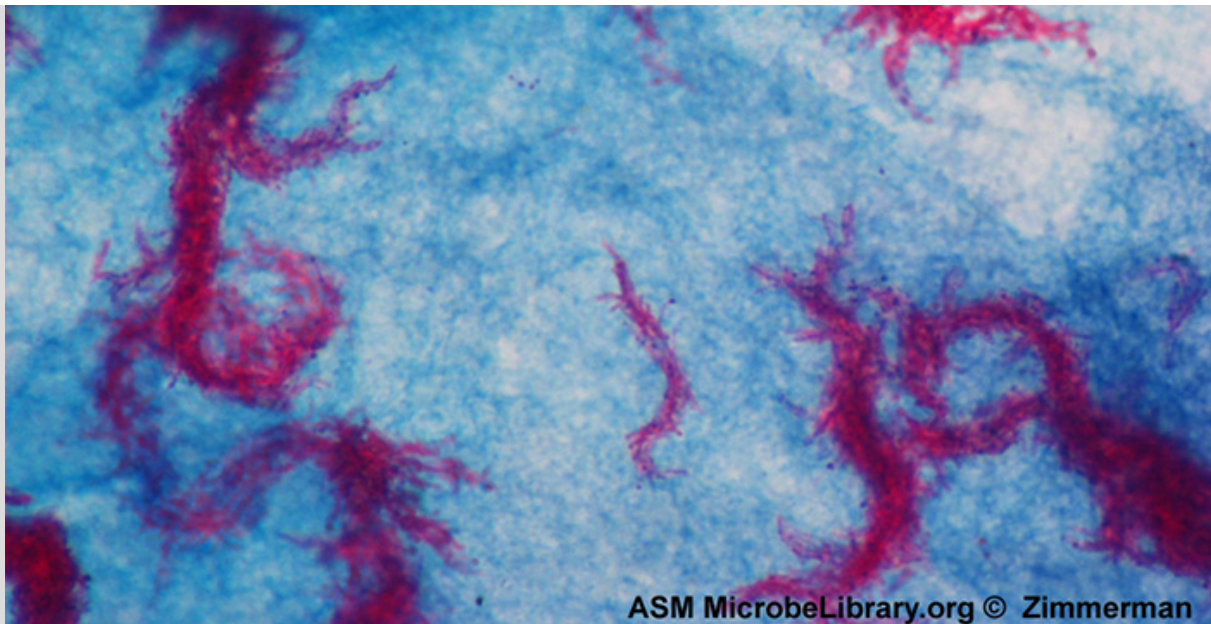
- Why are acid-fast stains useful?

Note:

Using Microscopy to Diagnose Tuberculosis

Mycobacterium tuberculosis, the bacterium that causes tuberculosis, can be detected in specimens based on the presence of acid-fast bacilli. Often, a smear is prepared from a sample of the patient's sputum and then stained using the Ziehl-Neelsen technique ([\[link\]](#)). If acid-fast bacteria are confirmed, they are generally cultured to make a positive identification. Variations of this approach can be used as a first step in determining whether *M. tuberculosis* or other acid-fast bacteria are present, though samples from elsewhere in the body (such as urine) may contain other *Mycobacterium* species.

An alternative approach for determining the presence of *M. tuberculosis* is immunofluorescence. In this technique, fluorochrome-labeled antibodies bind to *M. tuberculosis*, if present. Antibody-specific fluorescent dyes can be used to view the mycobacteria with a fluorescence microscope.



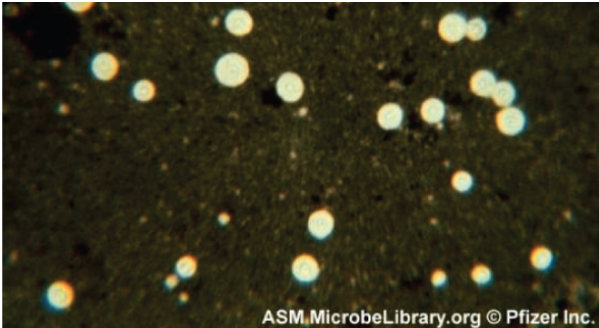
Ziehl-Neelsen staining has rendered these *Mycobacterium tuberculosis* cells red and the surrounding growth indicator medium blue. (credit: modification of work by American Society for Microbiology)

Capsule Staining

Certain bacteria and yeasts have a protective outer structure called a capsule. Since the presence of a capsule is directly related to a microbe's virulence (its ability to cause disease), the ability to determine whether cells in a sample have capsules is an important diagnostic tool. Capsules do not absorb most basic dyes; therefore, a negative staining technique (staining around the cells) is typically used for **capsule staining**. The dye stains the background but does not penetrate the capsules, which appear like halos around the borders of the cell. The specimen does not need to be heat-fixed prior to negative staining.

One common negative staining technique for identifying encapsulated yeast and bacteria is to add a few drops of India ink or nigrosin to a specimen.

Other capsular stains can also be used to negatively stain encapsulated cells ([link](#)). Alternatively, positive and negative staining techniques can be combined to visualize capsules: The positive stain colors the body of the cell, and the negative stain colors the background but not the capsule, leaving halo around each cell.



(a)



(b)

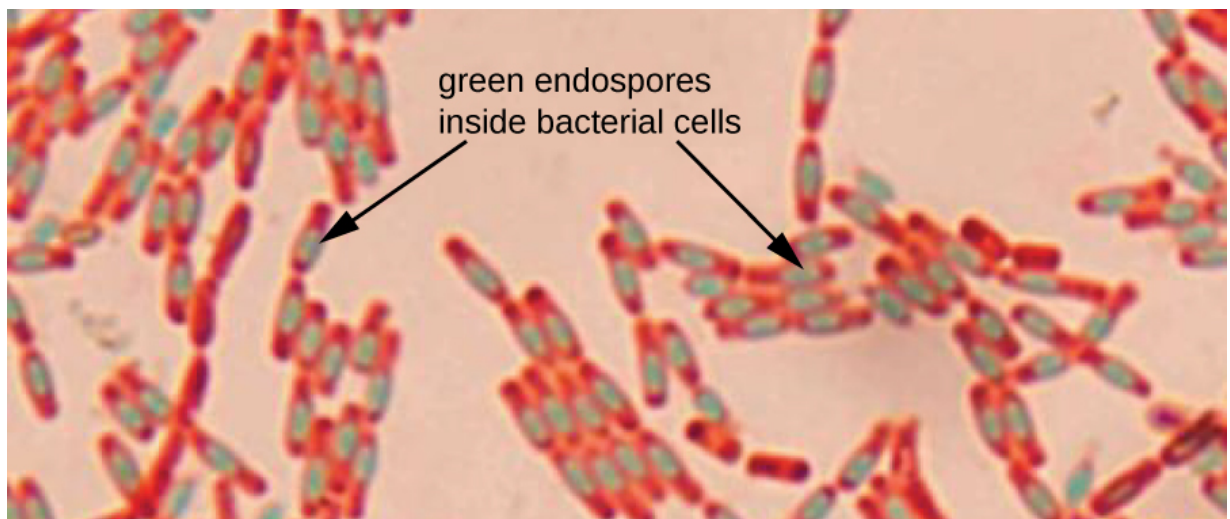
(a) India-ink was used to stain the background around these cells of the yeast *Cryptococcus neoformans*. The halos surrounding the cells are the polysaccharide capsules. (b) Crystal violet and copper sulfate dyes cannot penetrate the encapsulated *Bacillus* cells in this negatively stained sample. Encapsulated cells appear to have a light-blue halo. (credit a: modification of work by American Society for Microbiology; credit b: modification of work by American Society for Microbiology)

Note:

- How does negative staining help us visualize capsules?

Endospore Staining

Endospores are structures produced within certain bacterial cells that allow them to survive harsh conditions. Gram staining alone cannot be used to visualize endospores, which appear clear when Gram-stained cells are viewed. **Endospore staining** uses two stains to differentiate endospores from the rest of the cell. The Schaeffer-Fulton method (the most commonly used endospore-staining technique) uses heat to push the primary stain (malachite green) into the endospore. Washing with water decolorizes the cell, but the endospore retains the green stain. The cell is then counterstained pink with safranin. The resulting image reveals the shape and location of endospores, if they are present. The green endospores will appear either within the pink vegetative cells or as separate from the pink cells altogether. If no endospores are present, then only the pink vegetative cells will be visible ([link](#)).



A stained preparation of *Bacillus subtilis* showing endospores as green and the vegetative cells as pink. (credit: modification of work by American Society for Microbiology)

Endospore-staining techniques are important for identifying *Bacillus* and *Clostridium*, two genera of endospore-producing bacteria that contain clinically significant species. Among others, *B. anthracis* (which causes

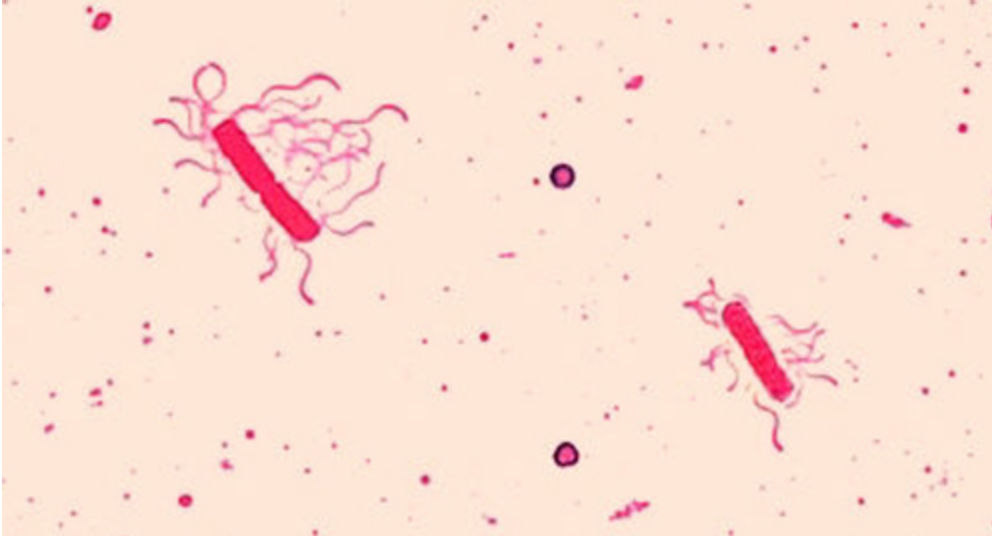
anthrax) has been of particular interest because of concern that its spores could be used as a bioterrorism agent. *C. difficile* is a particularly important species responsible for the typically hospital-acquired infection known as “C. diff.”

Note:

- Is endospore staining an example of positive, negative, or differential staining?

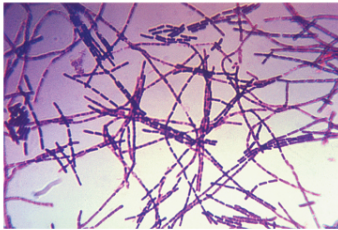
Flagella Staining

Flagella (singular: flagellum) are tail-like cellular structures used for locomotion by some bacteria, archaea, and eukaryotes. Because they are so thin, flagella typically cannot be seen under a light microscope without a specialized **flagella staining** technique. Flagella staining thickens the flagella by first applying mordant (generally tannic acid, but sometimes potassium alum), which coats the flagella; then the specimen is stained with pararosaniline (most commonly) or basic fuchsin ([\[link\]](#)).

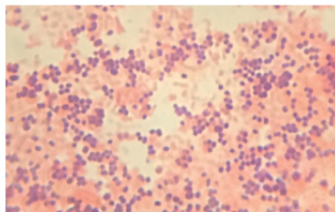
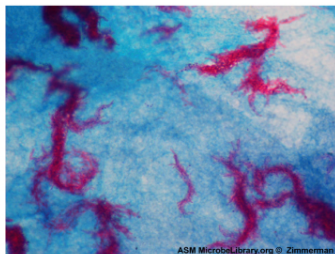
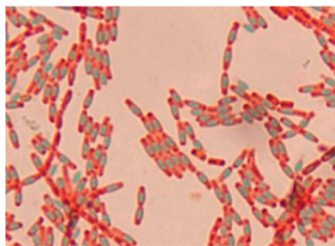
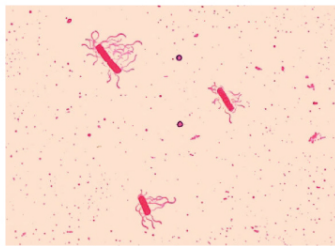
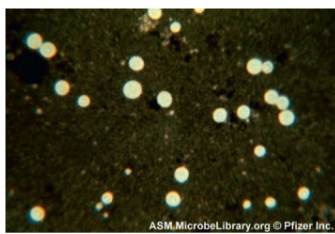


A flagella stain of *Bacillus cereus*, a common cause of foodborne illness, reveals that the cells have numerous flagella, used for locomotion. (credit: modification of work by Centers for Disease Control and Prevention)

Though flagella staining is uncommon in clinical settings, the technique is commonly used by microbiologists, since the location and number of flagella can be useful in classifying and identifying bacteria in a sample. When using this technique, it is important to handle the specimen with great care; flagella are delicate structures that can easily be damaged or pulled off, compromising attempts to accurately locate and count the number of flagella.

SIMPLE STAINS				
Stain Type	Specific Dyes	Purpose	Outcome	Sample Images
Basic stains	Methylene blue, crystal violet, malachite green, basic fuchsin, carbofuchsin, safranin	Stain negatively charged molecules and structures, such as nucleic acids and proteins	Positive stain	
Acidic stains	Eosin, acid fuchsin, rose bengal, Congo red	Stain positively charged molecules and structures, such as proteins	Can be either a positive or negative stain, depending on the cell's chemistry.	
Negative stains	India ink, nigrosin	Stains background, not specimen	Dark background with light specimen	

(credit “basic stains”: modification of work by Centers for Disease Control and Prevention; credit “Acidic stains”: modification of work by Roberto Danovaro, Antonio Dell’Anno, Antonio Pusceddu, Cristina Gambi, Iben Heiner, Reinhardt Mobjerg Kristensen; credit “Negative stains”: modification of work by Anh-Hue Tu)

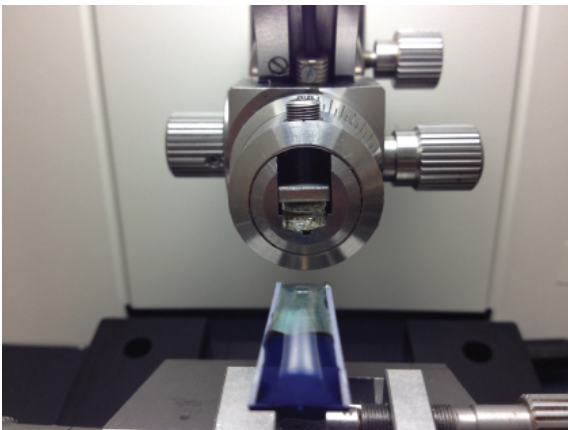
DIFFERENTIAL STAINS				
Stain Type	Specific Dyes	Purpose	Outcome	Sample Images
Gram stain	Uses crystal violet, Gram's iodine, ethanol (decolorizer), and safranin	Used to distinguish cells by cell-wall type (gram-positive, gram-negative)	Gram-positive cells stain purple/violet. Gram-negative cells stain pink.	
Acid-fast stain	After staining with basic fuchsin, acid-fast bacteria resist decolorization by acid-alcohol. Non acid-fast bacteria are counterstained with methylene blue.	Used to distinguish acid-fast bacteria such as <i>M. tuberculosis</i> , from non-acid-fast cells	Acid-fast bacteria are red; non-acid-fast cells are blue.	
Endospore stain	Uses heat to stain endospores with malachite green (Schaeffer-Fulton procedure), then cell is washed and counterstained with safranin.	Used to distinguish organisms with endospores from those without; used to study the endospore.	Endospores appear bluish-green; other structures appear pink to red.	
Flagella stain	Flagella are coated with a tannic acid or potassium alum mordant, then stained using either pararosaniline or basic fuchsin.	Used to view and study flagella in bacteria that have them.	Flagella are visible if present.	
Capsule stain	Negative staining with India ink or nigrosin is used to stain the background, leaving a clear area of the cell and the capsule. Counterstaining can be used to stain the cell while leaving the capsule clear.	Used to distinguish cells with capsules from those without.	Capsules appear clear or as halos if present.	

(credit “Gram stain”: modification of work by Nina Parker; credit “Acid-fast stain”: modification of work by American Society for Microbiology; credit “Endospore stain”: modification of work by

American Society for Microbiology; credit “Capsule stain” :
modification of work by American Society for Microbiology; credit
“Flagella stain”: modification of work by Centers for Disease Control
and Prevention)

Preparing Specimens for Electron Microscopy

Samples to be analyzed using a TEM must have very thin sections. But cells are too soft to cut thinly, even with diamond knives. To cut cells without damage, the cells must be embedded in plastic resin and then dehydrated through a series of soaks in ethanol solutions (50%, 60%, 70%, and so on). The ethanol replaces the water in the cells, and the resin dissolves in ethanol and enters the cell, where it solidifies. Next, **thin sections** are cut using a specialized device called an **ultramicrotome** ([link](#)). Finally, samples are fixed to fine copper wire or carbon-fiber grids and stained—not with colored dyes, but with substances like uranyl acetate or osmium tetroxide, which contain electron-dense heavy metal atoms.



(a)



(b)

(a) An ultramicrotome used to prepare specimens for a TEM. (b) A technician uses an ultramicrotome to slice a specimen into thin sections. (credit a: modification of work by “Frost Museum”/Flickr;

credit b: modification of work by U.S. Fish and Wildlife Service
Northeast Region)

When samples are prepared for viewing using an SEM, they must also be dehydrated using an ethanol series. However, they must be even drier than is necessary for a TEM. Critical point drying with inert liquid carbon dioxide under pressure is used to displace the water from the specimen. After drying, the specimens are sputter-coated with metal by knocking atoms off of a palladium target, with energetic particles. Sputter-coating prevents specimens from becoming charged by the SEM's electron beam.

Note:

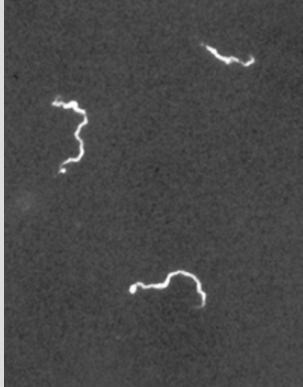
- Why is it important to dehydrate cells before examining them under an electron microscope?
- Name the device that is used to create thin sections of specimens for electron microscopy.

Note:

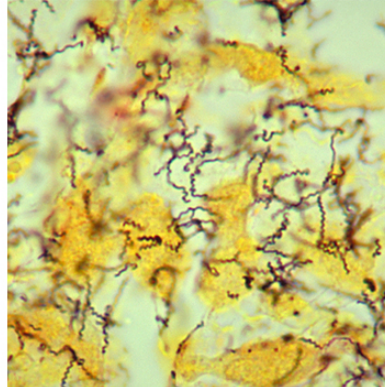
Using Microscopy to Diagnose Syphilis

The causative agent of syphilis is *Treponema pallidum*, a flexible, spiral cell (spirochete) that can be very thin ($<0.15\ \mu\text{m}$) and match the refractive index of the medium, making it difficult to view using brightfield microscopy. Additionally, this species has not been successfully cultured in the laboratory on an artificial medium; therefore, diagnosis depends upon successful identification using microscopic techniques and serology (analysis of body fluids, often looking for antibodies to a pathogen). Since fixation and staining would kill the cells, darkfield microscopy is typically used for observing live specimens and viewing their movements. However, other approaches can also be used. For example, the cells can be thickened with silver particles (in tissue sections) and observed using a light

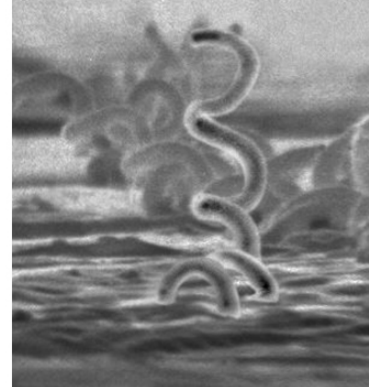
microscope. It is also possible to use fluorescence or electron microscopy to view *Treponema* ([link](#)).



(a)



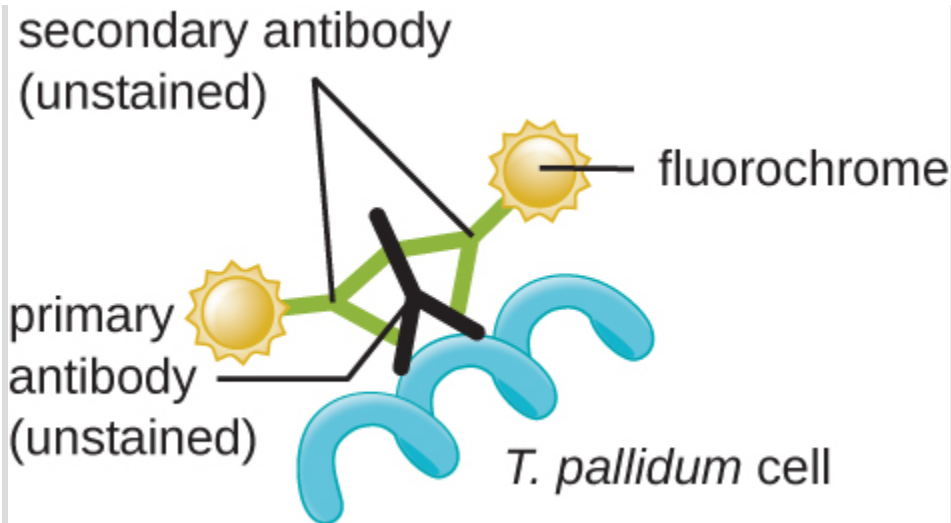
(b)



(c)

(a) Living, unstained *Treponema pallidum* spirochetes can be viewed under a darkfield microscope. (b) In this brightfield image, a modified Steiner silver stain is used to visualize *T. pallidum* spirochetes. Though the stain kills the cells, it increases the contrast to make them more visible. (c) While not used for standard diagnostic testing, *T. pallidum* can also be examined using scanning electron microscopy. (credit a: modification of work by Centers for Disease Control and Prevention; credit b: modification of work by Centers for Disease Control and Prevention; credit c: modification of work by Centers for Disease Control and Prevention)

In clinical settings, indirect immunofluorescence is often used to identify *Treponema*. A primary, unstained antibody attaches directly to the pathogen surface, and secondary antibodies “tagged” with a fluorescent stain attach to the primary antibody. Multiple secondary antibodies can attach to each primary antibody, amplifying the amount of stain attached to each *Treponema* cell, making them easier to spot ([link](#)).



Indirect immunofluorescence can be used to identify *T. pallidum*, the causative agent of syphilis, in a specimen.

Preparation and Staining for Other Microscopes

Samples for fluorescence and confocal microscopy are prepared similarly to samples for light microscopy, except that the dyes are fluorochromes. Stains are often diluted in liquid before applying to the slide. Some dyes attach to an antibody to stain specific proteins on specific types of cells (immunofluorescence); others may attach to DNA molecules in a process called fluorescence in situ hybridization (FISH), causing cells to be stained based on whether they have a specific DNA sequence.

Sample preparation for two-photon microscopy is similar to fluorescence microscopy, except for the use of infrared dyes. Specimens for STM need to be on a very clean and atomically smooth surface. They are often mica coated with Au(111). Toluene vapor is a common fixative.

Note:

- What is the main difference between preparing a sample for fluorescence microscopy versus light microscopy?

Note:

Cornell University's [Case Studies in Microscopy](#) offers a series of clinical problems based on real-life events. Each case study walks you through a clinical problem using appropriate techniques in microscopy at each step.

Note:**Resolution**

From the results of the Gram stain, the technician now knows that Cindy's infection is caused by spherical, gram-positive bacteria that form grape-like clusters, which is typical of staphylococcal bacteria. After some additional testing, the technician determines that these bacteria are the medically important species known as *Staphylococcus aureus*, a common culprit in wound infections. Because some strains of *S. aureus* are resistant to many antibiotics, skin infections may spread to other areas of the body and become serious, sometimes even resulting in amputations or death if the correct antibiotics are not used.

After testing several antibiotics, the lab is able to identify one that is effective against this particular strain of *S. aureus*. Cindy's doctor quickly prescribes the medication and emphasizes the importance of taking the

entire course of antibiotics, even if the infection appears to clear up before the last scheduled dose. This reduces the risk that any especially resistant bacteria could survive, causing a second infection or spreading to another person.

Go back to the [previous](#) Clinical Focus box.

Note:**Microscopy and Antibiotic Resistance**

As the use of antibiotics has proliferated in medicine, as well as agriculture, microbes have evolved to become more resistant. Strains of bacteria such as methicillin-resistant *S. aureus* (MRSA), which has developed a high level of resistance to many antibiotics, are an increasingly worrying problem, so much so that research is underway to develop new and more diversified antibiotics.

Fluorescence microscopy can be useful in testing the effectiveness of new antibiotics against resistant strains like MRSA. In a test of one new antibiotic derived from a marine bacterium, MC21-A (bromophene), researchers used the fluorescent dye SYTOX Green to stain samples of MRSA. SYTOX Green is often used to distinguish dead cells from living cells, with fluorescence microscopy. Live cells will not absorb the dye, but cells killed by an antibiotic will absorb the dye, since the antibiotic has damaged the bacterial cell membrane. In this particular case, MRSA bacteria that had been exposed to MC21-A did, indeed, appear green under the fluorescence microscope, leading researchers to conclude that it is an effective antibiotic against MRSA.

Of course, some argue that developing new antibiotics will only lead to even more antibiotic-resistant microbes, so-called superbugs that could spawn epidemics before new treatments can be developed. For this reason, many health professionals are beginning to exercise more discretion in prescribing antibiotics. Whereas antibiotics were once routinely prescribed for common illnesses without a definite diagnosis, doctors and hospitals are much more likely to conduct additional testing to determine whether an antibiotic is necessary and appropriate before prescribing.

A sick patient might reasonably object to this stingy approach to prescribing antibiotics. To the patient who simply wants to feel better as

quickly as possible, the potential benefits of taking an antibiotic may seem to outweigh any immediate health risks that might occur if the antibiotic is ineffective. But at what point do the risks of widespread antibiotic use supersede the desire to use them in individual cases?

Key Concepts and Summary

- Samples must be properly prepared for microscopy. This may involve **staining, fixation**, and/or cutting **thin sections**.
- A variety of staining techniques can be used with light microscopy, including **Gram staining, acid-fast staining, capsule staining, endospore staining**, and **flagella staining**.
- Samples for TEM require very thin sections, whereas samples for SEM require sputter-coating.
- Preparation for fluorescence microscopy is similar to that for light microscopy, except that fluorochromes are used.

Multiple Choice

Exercise:

Problem: What mordant is used in Gram staining?

- A. crystal violet
- B. safranin
- C. acid-alcohol
- D. iodine

Solution:

D

Exercise:

Problem:

What is one difference between specimen preparation for a transmission electron microscope (TEM) and preparation for a scanning electron microscope (SEM)?

- A. Only the TEM specimen requires sputter coating.
- B. Only the SEM specimen requires sputter-coating.
- C. Only the TEM specimen must be dehydrated.
- D. Only the SEM specimen must be dehydrated.

Solution:

B

Fill in the Blank**Exercise:****Problem:**

Ziehl-Neelsen staining, a type of _____ staining, is diagnostic for *Mycobacterium tuberculosis*.

Solution:

acid-fast

Exercise:**Problem:**

The _____ is used to differentiate bacterial cells based on the components of their cell walls.

Solution:

Gram stain

Short Answer

Exercise:

Problem:

How could you identify whether a particular bacterial sample contained specimens with mycolic acid-rich cell walls?

Critical Thinking

Exercise:

Problem:

You use the Gram staining procedure to stain an L-form bacterium (a bacterium that lacks a cell wall). What color will the bacterium be after the staining procedure is finished?

Carbohydrate Fermentation
lab procedure

Carbohydrate Fermentation

Introduction

During fermentation most bacteria convert carbohydrates into organic acids, with or without the production of gas. One can test for this by adding a pH indicator and an inverted tube (a Durham tube) to the culture medium. We will use phenol red as the pH indicator. If acid is produced the phenol red will turn yellow (pH below 6.8). Any gas produced will form a bubble in the inverted tube.

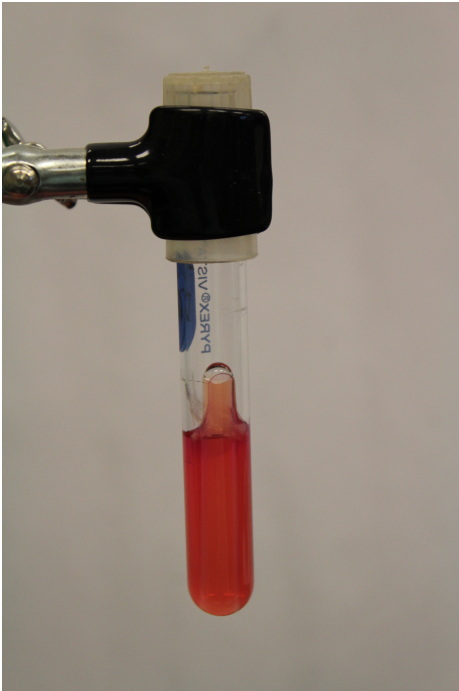
Procedure

- 1. Obtain a tube of phenol red glucose, lactose, sucrose broth, each with an inverted Durham tube.
- 2. Inoculate each with your assigned organism by swishing it in the broth.
- 3. Incubate for at least 24 hours and record the results.

Interpretation

pH/Gas Production	Color	Result
Alkaline or no change	Red/fuchsia	Negative (fig. 1)
Acidic without gas	Yellow	Positive for fermentation

pH/Gas Production	Color	Result
Acidic with gas	Yellow with bubble	Positive for fermentation with gas production (fig. 2)



Starch Agar lab procedure

Starch Agar

Introduction

Amylase is an exoenzyme (an enzyme released from the bacteria into its surroundings) that breaks starch by cleaving large starch molecules into monosaccharide and disaccharide units that can then enter the cell and be metabolized.

Procedure

1. Obtain a deep of starch agar, melt it and prepare a Petri plate.
2. After the starch agar has solidified, using the inoculation loop, make one streak off center of the plate with your assigned bacterium.
3. Incubate the plate upside down for at least 48 hours.
4. After the incubation period, flood the plate with iodine.

Interpretation

Iodine reacts with starch resulting in a blue/blue black color. Therefore, any areas containing starch will turn dark blue/black/purple. Areas free of starch will remain clear. In a positive reaction, bacteria producing amylase will have a clear halo around them.

Gelatin Agar lab procedure

Gelatin Agar

Introduction

Gelatinase is an exoenzyme that digests the protein gelatin into amino acids and short-chain peptides. There are two ways to test for the production of gelatinase. One method, the gelatin liquefaction test, examines the ability of gelatinase to liquefy nutrient gelatin. However, the tubes need to be incubated for up to 7 days. However, the test that we will use takes advantage of the ability of strong acids to denature proteins and form a visible precipitate.

Procedure

1. Obtain a deep of gelatin agar, melt it and prepare a Petri plate.
2. After the gelatin agar has solidified, using an inoculating loop, make one streak of center of the plate with your assigned bacterium.
3. Incubate the plate upside down for at least 48 hours.
4. After the incubation period, flood the gelatin agar plate with saturated ammonium sulfate.

Interpretation

Saturated ammonium sulfate will form a white, cloudy precipitate with any remaining gelatin. Areas where the gelatin has been digested will remain clear. In a positive reaction, bacteria producing gelatinase will have a clear halo around the streak.

Catalase lab procedure

Catalase

Introduction

Catalase is an enzyme that breaks hydrogen peroxide into water and oxygen. Hydrogen peroxide is a common byproduct of metabolic reactions occurring in an environment where water and oxygen are present, but it is toxic to cells. Therefore, most organisms that survive in the presence of oxygen contain enzymes to degrade the hydrogen peroxide.

Procedure

1. Start with a clean microscope slide and place a drop of hydrogen peroxide on it.
2. Using an inoculating loop, remove some of your assigned organism and put the loop with the organism on it into the drop of hydrogen peroxide. Do not stir.
3. Observe the drop of hydrogen peroxide.

Interpretation

Bubbles will form around the organism on the loop if catalase is produced

Motility Agar lab procedure

Motility Agar

Introduction

Because the flagellar staining procedure often produces poor results in the hands of novices, other tests for motility (and the presence of flagella) have been developed. One type of test involves using a semi-solid medium that allows motile bacteria to penetrate.

Procedure

1. Obtain a deep of motility agar.
2. Using an inoculation needle, stab straight into the deep about 2/3 of the way down and out the same pathway as quickly as possible with your assigned bacterium.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, examine your tube.

Interpretation

If the organism is motile, growth will 'fan' out from the stab or the entire tube may look cloudy. If the organism is non-motile, growth remains confined to the stab line (see fig. below).



SIM Agar lab procedure

SIM Agar

Introduction

SIM (sulfide, indole, motility) medium is an example of a multi-test medium, that is, it tests more than one aspect of the bacterium's metabolism at a time. In this case, the production of hydrogen sulfide, the formation of indole, and motility.

Procedure

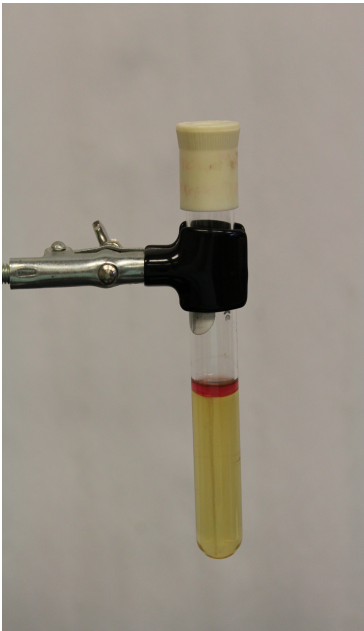
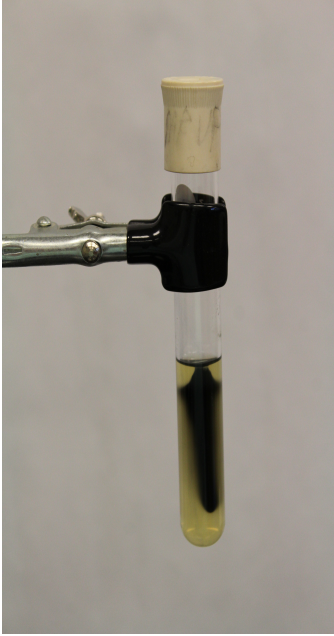
1. Obtain a deep of SIM medium.
2. Using an inoculating needle, stab the medium about 2/3 of the way down and out the same pathway as quickly as possible with your assigned organism.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, examine your tube.

Interpretation

Hydrogen sulfide (H_2S) production is indicated by a black color in the medium (fig. 1 below).

Indole production is indicated by a red ring on the surface of the deep after adding Kovac's reagent (fig. 2 below).

Motility is indicated by the ability of the organism to 'fan' away from the streak. Or, the entire tube may appear cloudy when compared to an uninoculated control. If the organism is non-motile, the growth will only appear along the stab line (fig. 3 below).





Tryptone Broth lab procedure

Tryptone Broth

Introduction

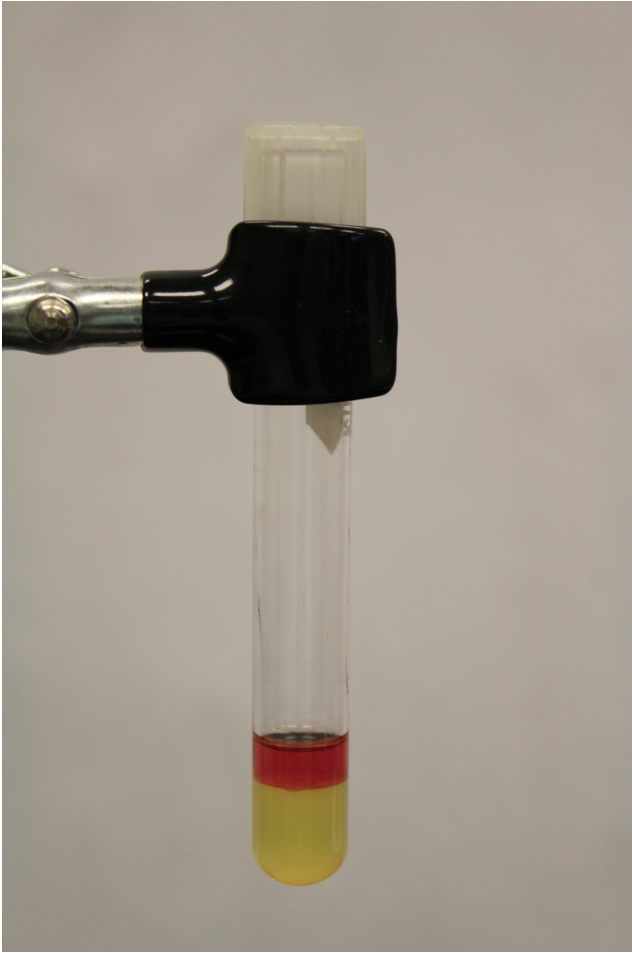
Bacterial tryptophanase converts the amino acid tryptophan into pyruvate, ammonia, and indole. The medium used to test for this enzyme is 1% tryptone in water.

Procedure

1. Obtain a tube of tryptone broth.
2. Using an inoculating loop, swish some of your assigned organism in the broth.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, add several drops of Kovac's reagent to the tube.

Interpretation

The chemicals in Kovac's reagent react with indole to produce a red color. In a positive test, a red layer will float at the surface of the broth (see fig. below).



MR-VP Broth lab procedure

Methyl Red - Voges-Proskauer (MR-VP) Broth

Introduction

When glucose is fermented, a variety of products are possible. This is a test used to determine some of those products. Most organisms differentiated by this test convert the glucose to acids. Some bacteria continue to produce more acid in 'mixed acid fermentation.' Some genera use the glucose but produce end products with a more neutral pH like those that result from 'butanediol fermentation.'

Procedure

1. Obtain one tube of MR-VP broth.
2. Using an inoculating loop, swish some of your assigned organism in the broth.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, vortex the tube and pour half of the broth into another clean test tube.
5. Complete the tests on the two individual tubes as follows:

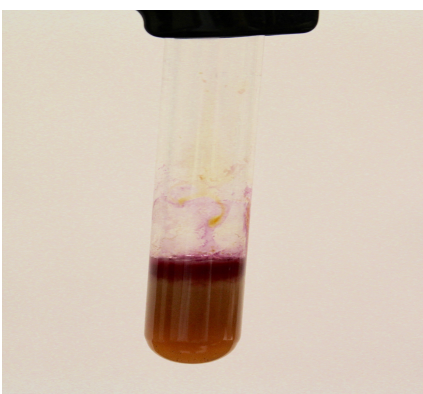
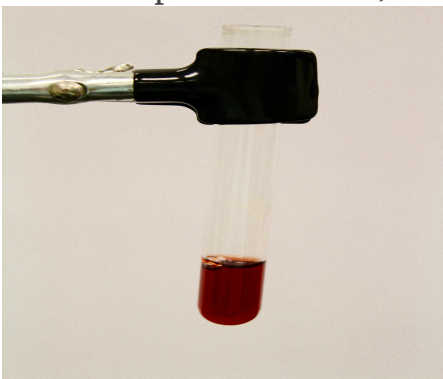
MR – to one tube add a drop or two of the pH indicator methyl red and swirl.

VP – To the other tube add three drops of Barritt's 1/A reagent (5% alpha-naphthol solution) and a drop of Barritt's 2/B reagent (40% potassium hydroxide solution). Shake vigorously and watch the tube over the **next hour or two**. Alternatively, if not shaken only the air-broth interface might indicate a change in color.

Interpretation

MR – If the tube turns red, the test is positive for mixed-acid fermentation (one or more organic acids formed during the fermentation of glucose)[see fig. 1 below].

VP – If the tube (or interface) turns pink or red, the test is positive for acetoin a precursor of 2,3-butanediol (see fig. 2 below).



Simmons Citrate Agar lab procedure

Simmons Citrate Agar

Introduction

Simmons Citrate Agar is a defined medium that tests for an organism's ability to use citrate as its carbon source and ammonia as its nitrogen source. Only bacteria that can transport citrate into the cell from the medium grow well in Citrate Agar.

Procedure

1. Obtain a slant of Simmons Citrate Agar.
2. Using an inoculating needle, stab your assigned organism into the medium, then zigzag the needle back and forth up the surface of the slant.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, examine the slant.

Interpretation

In a positive test, there will be heavy growth and the slant will turn royal blue (see fig. below).



Urea Broth lab procedure

Urea Broth

Introduction

Some bacteria are able to break urea into carbon dioxide and ammonia by means of the exoenzyme urease.

Procedure

1. Obtain a tube of urea broth.
2. Using an inoculating loop, swish some of your assigned organism into the broth.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, note the color of the broth.

Interpretation

If urease is produced, the medium will be cerise (see fig. below).



Phenylalanine Agar lab procedure

Phenylalanine Agar

Introduction

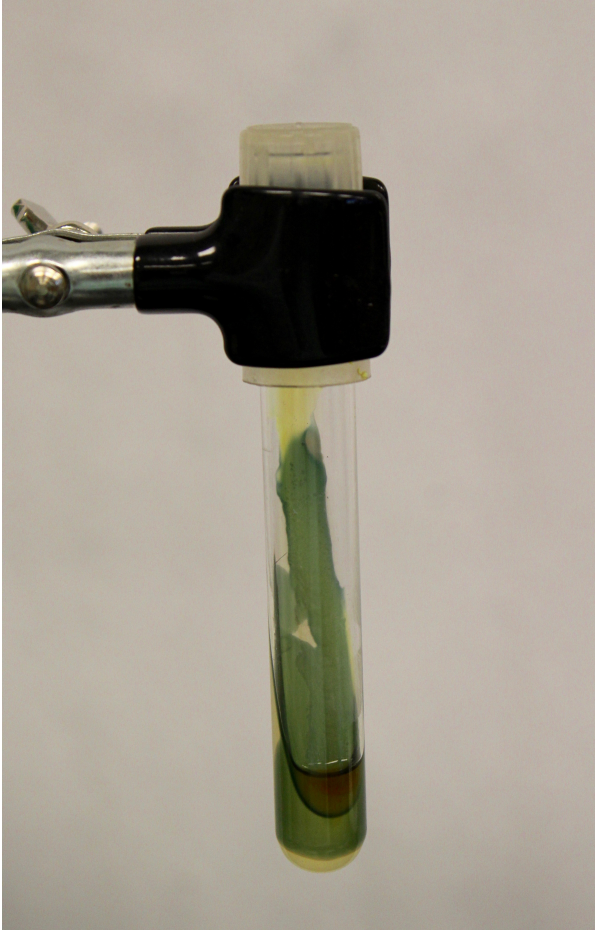
Bacteria that produce phenylalanine deaminase are able to remove the amino group from the amino acid phenylalanine yielding ammonia and phenylpyruvic acid.

Procedure

1. Obtain a slant of phenylalanine agar.
2. Using an inoculating loop, zigzag up the slant with your assigned organism.
3. Incubate the tube for at least 48 hours.
4. After the incubation period, add 3-5 drops of FeCl_3 (ferric chloride) to the tube, making sure that it touches the slant.

Interpretation

Phenylpyruvic acid turns green in the presence of ferric chloride indicating the production of phenylalanine deaminase (see fig. below).



Triple-Sugar Iron Agar lab procedure

Triple-Sugar Iron Agar

Introduction

Triple-sugar iron agar (TSI agar) is another example of a multi-test agar. It tests for the fermentation, with or without gas production, of glucose, lactose, and sucrose. It also tests for the production of hydrogen sulfide from amino acids. Phenol red is the pH indicator used in this test medium.

Procedure

1. Obtain a slant of TSIA.
2. Using an inoculating needle, stab your assigned organism into the butt of the TSIA slant. As you remove the inoculating needle, drag it in a zigzag pattern up the surface of the slant portion of the tube.
3. Incubate the slant for 24-48 hours.
4. After the incubation period, record any changes in the tube.

Interpretation

Review your results from Carbohydrate Fermentation and note the following:

Slant color/butt color: Slant color indicates the fermentation of lactose and/or sucrose.

Butt color indicates the fermentation of glucose.

Production of gas: Agar shows bubbles or may split.

Production of H₂S: H₂S formation is indicated by a blackening of the medium.



A/A, $\text{H}_2\text{S} +$,
Gas +



K/A, $\text{H}_2\text{S} +$,
Gas +

Levine EMB Agar lab procedure

Levine EMB Agar

Introduction

Levine EMB (eosin methylene blue) agar is an example of a selective and differential medium. This means that only some bacteria will grow on this agar and that the appearance of those that do grow will be different. In particular, EMB agar inhibits the growth of Gram-positive bacteria and helps differentiate some of the Gram-negative rods.

Procedure

1. Obtain a deep of EMB agar, melt it and prepare a Petri plate.
2. After the agar has solidified, using an inoculating loop and your assigned organism, streak the plate for the isolation of colonies.
3. Incubate the plate upside down for at least 48 hours.
4. After the incubation period, record any color changes.

Interpretation

EMB agar contains lactose and the dyes eosin and methylene blue. The fermentation of lactose by some Gram-negative rods produces acidic products that react with the dyes to produce colored colonies.

Escherichia coli colonies produce a green, metallic sheen.

Enterobacter aerogenes colonies are a pink/buff color with darker centers.

Pseudomonas aeruginosa colonies are colorless indicating no fermentation.

Laboratory Safety Contract (Microbiology)
lab safety contract required of all microbiology students

**MICROBIOLOGY FOR ALLIED HEALTH STUDENTS
LABORATORY SAFETY CONTRACT**

Microbiology is a hands-on laboratory class. You will be doing many laboratory activities which require the use of potentially hazardous bacteria and chemicals. Safety in the microbiology laboratory is #1 priority of the instructor and the student. To ensure a safe microbiology laboratory, a list of rules has been developed and provided to you in this student safety contract. These rules must be followed at all times.

General Guidelines

1. Conduct yourself in a responsible manner at all times in the laboratory.
2. Never work alone. No student may work in the laboratory without an instructor present.
3. Open cuts and wounds **MUST** be bandaged before you enter the lab.
4. **NEVER** bring food or beverages into the laboratory. (YOU WILL BE ASKED TO LEAVE FOR THAT LAB). Do not eat food, drink beverages, or chew gum or tobacco in the laboratory. Do not use laboratory glassware as containers for food or beverages. ***Please be aware that the laboratory areas are under constant surveillance.***
5. Follow all written and verbal instructions carefully. If you do not understand a direction or part of a procedure, ask the instructor before proceeding.
6. Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedure or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.

7. Be prepared for your work in the laboratory. Read all procedures thoroughly before entering the laboratory.
8. Never fool around in the laboratory. Horseplay, practical jokes and pranks are dangerous and are prohibited.
9. Observe good housekeeping practices. Work areas should be kept clean and tidy at all times. Allow adequate workspace. Keep the aisles clear. Keep lab tables clear of clutter.
10. Know the location and operating procedures of all safety equipment including the first aid kit, fire extinguisher, fire blanket and eye wash station. Know where the fire alarms and exits are located.
11. Always work in a well-ventilated area. Use the fume hood when working with volatile substances or poisons.
12. Be alert and proceed with caution at all times in the laboratory. Notify the instructor immediately of any unsafe conditions you observe.
13. Dispose of all biological waste properly. Sinks are to be used only for water and those solutions designated by the instructor. Matches, filter papers and all other insoluble material are to be disposed of in proper waste containers, not in the sink.
14. Labels and equipment instructions must be read carefully before use.
15. Keep hands away from face, eyes, mouth and body while working in microbiology laboratory. Wash your hands with soap and water before and after performing all experiments. Clean with disinfectant, and wipe dry all work surfaces and apparatus at the end of the experiment. Return all equipment clean and in working order to the proper storage area.
16. **ALWAYS** disinfect your bench top **BEFORE AND AFTER** each laboratory session.
17. **ALWAYS** wash your hands before beginning your work **AND** at the end of each laboratory session before leaving the room.

18. Never leave an experiment or lab activity unattended. Extinguish burners when you are away from your work area. Experiments must be personally monitored at all times. Do not wander around the building or campus while laboratory experiments are being performed.

Clothing

19. Any time microorganisms, chemicals, heat or glassware are used, students will wear laboratory goggles. **There will be no exceptions to this rule!**

20. Contact lenses should not be worn in the laboratory unless you have permission from your instructor.

21. Wear proper attire at all times in the laboratory:

- a. Avoid loose or baggy clothing, dangling jewelry, etc.
- b. Shorts and miniskirts should not be worn.
- c. Shoes must completely cover the foot. No sandals are allowed.
- d. Long hair must be tied back.
- e. You need to wear protective covering such as a lab coat to safeguard your body/clothing. If so, do not take your lab coat home with you; keep it in your drawer. If you want to take it home to wash it, bring a plastic bag in which to carry it home.

22. Lab aprons have been provided for your use and should be worn during laboratory activities.

Accidents and Injuries

23. **Report any accident** (spill, breakage, etc.) or injury (cut, burn, etc.) **to the instructor immediately**, no matter how trivial it may appear.

24. If you spill or drop a culture, after notifying the instructor, place a paper towel over the spill and pour disinfectant on the towel. Wait for 15 minutes

then clean the spill with fresh paper towels. Remember to place paper towels in waste baskets and wash your hands carefully. Dispose of any broken glass properly.

Handling Bacteria and Chemicals

25. All bacteria and chemicals in the laboratory are to be considered dangerous. Do not touch, taste or smell any bacterial culture or chemical unless specifically told to do so.

26. For bacteria or chemicals ingested, see the lab instructor immediately.

27. Check the label on cultures and chemical bottles twice before removing any of the contents. Take only as much of the bacterial culture or chemical as you need.

28. Never return unused chemicals to their original containers.

29. Never use mouth suction to fill a pipet. Use a rubber bulb or pipet pump. Always keep the pipet pointed away from your body.

30. Never dispense flammable liquids such as ethanol anywhere near an open flame or source of heat.

31. Never remove bacteria, chemicals or other equipment from the laboratory.

32. Take great care when transporting cultures and chemicals from one part of laboratory to other. Hold them securely and walk carefully. All cultures should be in a test tube rack.

Handling Glassware and Equipment

33. Never handle broken glass with your bare hands. Use a brush and dustpan to clean up broken glass. Place broken or waste glassware in the designated glass disposal container. If it is contaminated, it must be autoclaved first. Notify the instructor.

34. Examine glassware before each use. Never use chipped or cracked glassware. Never use dirty glassware.
35. Do not immerse hot glassware in cold water or put it directly from a hot plate to the cooler countertop; it may shatter.
36. Report damaged electrical equipment immediately. Look for things like frayed cords, exposed wires and loose connections. Do not use damaged electrical equipment.
37. If you do not understand how to use a piece of equipment, ask the instructor for help.

Heating Substances

38. Exercise extreme caution when using a gas burner. Take care that hair, clothing and hands are a safe distance from the flame at all times. Never reach over an exposed flame.
39. Never leave a lit burner unattended. Never leave anything that is being heated unattended. Always turn the burner or hot plate off when not in use.
40. Heated metals and glass remain very hot for a long time. They should be set aside to cool and picked up with caution. Use tongs if necessary.
41. Determine if an object is hot by bringing the back of your hand close to it prior to grasping it.

Disposal

42. Discard all cultures, petri-plates, and used glassware in the container labeled **contaminated** or **biohazard**. This container will later be autoclaved.
43. **NEVER** place contaminated pipettes on the bench top.
44. **NEVER** place contaminated inoculating loops on the bench top.

45. **NEVER** discard contaminated cultures, Petri dishes, glassware, pipettes, tubes, or slides in the trash can.

46. **NEVER** discard contaminated liquids or liquid cultures in the sink.

MSDS

47. Material safety data sheets are available (in a CD) in the laboratory for all chemicals used.

Other

48. Inform the instructor if you are or become pregnant during the semester.

QUESTIONS:

1. Do you wear contact lenses? Yes _____ No _____

2. Are you color blind? Yes _____ No _____

3. Do you have any allergies? Yes _____ No _____

If so, list specific allergies:

AGREEMENT

I, _____ (Print your name) have read and agree to follow all of the safety rules set forth in this contract. I realize that I must obey these rules to insure my own safety and that of my fellow students and instructors. I will cooperate to the fullest extent with my instructor and fellow students to maintain a safe lab environment. I will also closely follow the oral and written instructions provided by the instructor. I am aware that any violation of this safety contract that results in unsafe conduct in the laboratory may result in being removed from the laboratory and/or receiving a failing grade.

I also agree not to hold the instructor or the institution responsible for any personal injury caused by violation of the rules of this contract.

__ Student Signature and Date

__ Witness Signature

Updated Summer 2017

Glossary

- **454 sequencing (pyrosequencing)** a next generation sequencing technique in which fragmented DNA has DNA adapters attached, is amplified by PCR, is attached to a bead, and then placed into a well with sequencing reagents, and the flash of light produced by the release of pyrophosphate on addition of a nucleotide is monitored
- **5' cap** methylguanosine nucleotide added to 5' end of a eukaryotic primary transcript
- **70S ribosome** a ribosome composed of 50S and 30S subunits
- **80S ribosome** cytoplasmic eukaryotic ribosome composed of 60S and 40S subunits

A

- **α -helix** secondary structure consisting of a helix stabilized by hydrogen bonds between nearby amino acid residues in a polypeptide
- **A (aminoacyl) site** functional site of an intact ribosome that binds incoming charged aminoacyl tRNAs
- **A-B exotoxin** class of exotoxin that contains A subunits, which enter the cell and disrupt cellular activities, and B subunits, which bind to host cell receptors
- **ABO blood group system** set of glycoprotein antigens found on the surface of red blood cells; the presence or absence of specific carbohydrates determining blood type
- **absorbance** when a molecule captures energy from a photon and vibrates or stretches, using the energy
- ***Acanthamoeba keratitis*** a condition characterized by damage to the cornea and possible blindness caused by parasitic infection of the protozoan *Acanthamoeba*
- **acellular** not made of cells
- **acid-fast stain** a stain that differentiates cells that have waxy mycolic acids in their gram-positive cell walls

- **acidic dye** a chromophore with a negative charge that attaches to positively charged structures
- **acidophile** organism that grows optimally at a pH near 3.0
- **acne** a skin disease in which hair follicles or pores become clogged, leading to the formation of comedones and infected lesions
- **acquired immunodeficiency syndrome (AIDS)** disease caused by HIV, characterized by opportunistic infections and rare cancers
- **actin** a protein that polymerizes to form microfilaments
- **activation energy** energy needed to form or break chemical bonds and convert a reactant or reactants to a product or products
- **activator** protein that increases the transcription of a gene in response to an external stimulus
- **active carrier** an infected individual who can transmit the pathogen to others regardless of whether symptoms are currently present
- **active immunity** stimulation of one's own adaptive immune responses
- **active site** location within an enzyme where substrate(s) bind
- **acute disease** disease of a relatively short duration that develops and progresses in a predictable pattern
- **acute glomerulonephritis** inflammation of the glomeruli of the kidney, probably resulting from deposition of immune complexes and an autoimmune response caused by self-antigen mimicry by a pathogen
- **acute necrotizing ulcerative gingivitis** a severe form of gingivitis, also called trench mouth
- **acute otitis media** inflammatory disease of the middle ear resulting from a microbial infection
- **acute rheumatic fever** sequela of streptococcal pharyngitis; comorbidities include arthritis and carditis
- **acute-phase proteins** antimicrobial molecules produced by liver cells in response to pathogen-induced stimulation events
- **acyclovir** antiviral guanosine analog; inhibits DNA replication
- **adaptive immunity** third-line defense characterized by specificity and memory
- **Addison disease** autoimmune disease affecting adrenal gland function
- **adenine** purine nitrogenous base found in nucleotides
- **adenosine diphosphate (ADP)** nucleotide derivative and relative of ATP containing only one high-energy phosphate bond

- **adenosine monophosphate (AMP)** adenine molecule bonded to a ribose molecule and to a single phosphate group, having no high-energy phosphate bonds
- **adenosine triphosphate (ATP)** energy currency of the cell; a nucleotide derivative that safely stores chemical energy in its two high-energy phosphate bonds
- **adhesins** molecules on the surface of pathogens that promote colonization of host tissue
- **adhesion** the capability of microbes to attach to host cells
- **aerobic respiration** use of an oxygen molecule as the final electron acceptor of the electron transport system
- **aerotolerant anaerobe** organism that does not use oxygen but tolerates its presence
- **affinity maturation** function of the immune system by which B cells, upon re-exposure to antigen, are selected to produce higher affinity antibodies
- **affinity** measure of how tightly an antibody-binding site binds to its epitope
- **aflatoxin** chemical produced by the fungus *Aspergillus flavus*; both a toxin and the most potent known natural carcinogen
- **African sleeping sickness** see *human African trypanosomiasis*
- **agarose gel electrophoresis** a method for separating populations of DNA molecules of varying sizes by differential migration rates caused by a voltage gradient through a horizontal gel matrix
- **agglutination** binding of different pathogen cells by Fab regions of the same antibody to aggregate and enhance elimination from body
- **agranulocytes** leukocytes that lack granules in the cytoplasm
- **alarmone** small intracellular derivative of a nucleotide that signals a global bacterial response (i.e., activating a regulon of operons) to an environmental stress
- **albendazole** antihelminthic drug of the benzimidazole class that binds to helminthic β -tubulin, preventing microtubule formation
- **algae** (singular: alga) any of various unicellular and multicellular photosynthetic eukaryotic organisms; distinguished from plants by their lack of vascular tissues and organs
- **alkaliphile** organism that grows optimally at pH above 9.0

- **alkylating agent** type of strong disinfecting chemical that acts by replacing a hydrogen atom within a molecule with an alkyl group, thereby inactivating enzymes and nucleic acids
- **allergen** antigen capable of inducing type I hypersensitivity reaction
- **allergy** hypersensitivity response to an allergen
- **allograft** transplanted tissue from an individual of the same species that is genetically different from the recipient
- **allosteric activator** molecule that binds to an enzyme's allosteric site, increasing the affinity of the enzyme's active site for the substrate(s)
- **allosteric site** location within an enzyme, other than the active site, to which molecules can bind, regulating enzyme activity
- **allylamines** class of antifungal drugs that inhibit ergosterol biosynthesis at an early point in the pathway
- **Alphaproteobacteria** class of Proteobacteria that are all oligotrophs
- **alveoli** cul-de-sacs or small air pockets within the lung that facilitate gas exchange
- **amantadine** antiviral drug that targets the influenza virus by preventing viral escape from endosomes upon host cell uptake, thus preventing viral RNA release and subsequent viral replication
- **amensalism** type of symbiosis in which one population harms the other but remains unaffected itself
- **Ames test** method that uses auxotrophic bacteria to detect mutations resulting from exposure to potentially mutagenic chemical compounds
- **amino acid** a molecule consisting of a hydrogen atom, a carboxyl group, and an amine group bonded to the same carbon. The group bonded to the carbon varies and is represented by an *R* in the structural formula
- **aminoacyl-tRNA synthetase** enzyme that binds to a tRNA molecule and catalyzes the addition of the correct amino acid to the tRNA
- **aminoglycosides** protein synthesis inhibitors that bind to the 30S subunit and interfere with the ribosome's proofreading ability, leading to the generation of faulty proteins that insert into and disrupt the bacterial cytoplasmic membrane
- **amoebiasis** intestinal infection caused by *Entamoeba histolytica*
- **amoebic dysentery** severe form of intestinal infection caused by *Entamoeba histolytica*, characterized by severe diarrhea with blood and mucus

- **amphipathic** a molecule containing both polar and nonpolar parts
- **amphitrichous** having two flagella or tufts of multiple flagella, with one flagellum or tuft located at each end of the bacterial cell
- **amphotericin B** antifungal drug of the polyene class that is used to treat several systemic fungal infections
- **amplitude** the height of a wave
- **anabolism** chemical reactions that convert simpler molecules into more complex ones
- **anaerobe chamber** closed compartment used to handle and grow obligate anaerobic cultures
- **anaerobe jar** container devoid of oxygen used to grow obligate anaerobes
- **anaerobic respiration** use of a non-oxygen inorganic molecule, like CO₂, nitrate, nitrite, oxidized iron, or sulfate, as the final electron acceptor at the end of the electron transport system
- **analytical epidemiology** study of disease outbreaks to establish associations between an agent and a disease state through observational studies comparing groups of individuals
- **anaphylactic shock** another term for anaphylaxis
- **anaphylaxis** systemic and potentially life-threatening type I hypersensitivity reaction
- **anergy** peripheral tolerance mechanism that prevents self-reactive T cells from being activated by self-antigens through lack of co-stimulation
- **annealing** formation of hydrogen bonds between the nucleotide base pairs of two single-stranded complementary nucleic acid sequences
- **anoxygenic photosynthesis** type of photosynthesis found in many photosynthetic bacteria, including the purple and green bacteria, where an electron donor other than H₂O is used to replace an electron lost by a reaction center pigment, resulting no oxygen production
- **anthrax** a disease caused by *Bacillus anthracis*; the cutaneous form causes a skin lesion to develop; gastrointestinal and inhalation anthrax have high mortality rates
- **antibiogram** compilation of the antimicrobial susceptibilities recorded for local bacterial strains, which is useful for monitoring local trends in antimicrobial resistance and aiding the prescription of appropriate empiric antibacterial therapy

- **antibiotic-associated diarrhea** diarrhea that develops after antibiotic treatment as a result of disruption to the normal microbiota; *C. difficile* is a particularly serious example
- **antibody screen** test to make sure that a potential blood recipient has not produced antibodies to antigens other than the ABO and Rh antigens
- **antibody** Y-shaped glycoprotein molecule produced by B cells that binds to specific epitopes on an antigen
- **antibody-dependent cell-mediated cytotoxicity (ADCC)** mechanism by which large pathogens are marked for destruction by specific antibodies and then killed by secretion of cytotoxins by natural killer cells, macrophages, or eosinophils
- **anticodon** three-nucleotide sequence of a mature tRNA that interacts with an mRNA codon through complementary base pairing
- **antigen (also, immunogen)** a molecule that stimulates an adaptive immune response
- **antigenic** able to stimulate an adaptive immune response
- **antigenic drift** form of slight antigenic variation that occurs because of point mutations in the genes that encode surface proteins
- **antigenic shift** form of major antigenic variation that occurs because of gene reassortment
- **antigenic variation** changing of surface antigens (carbohydrates or proteins) such that they are no longer recognized by the host's immune system
- **antigen-presenting cells (APC)** macrophages, dendritic cells, and B cells that process and present foreign pathogen antigens for the purpose of activating T cells and adaptive immune defenses
- **antimetabolites** compounds that are competitive inhibitors for bacterial metabolic enzymes
- **antimicrobial drugs** chemical compounds, including naturally produced drugs, semisynthetic derivatives, and synthetic compounds, that target specific microbial structures and enzymes, killing specific microbes or inhibiting their growth
- **antimicrobial peptides (AMPs)** class of nonspecific, cell-derived chemical mediators with broad-spectrum antimicrobial properties
- **antiparallel** two strands of DNA helix oriented in opposite directions; one strand is oriented in the 5' to 3' direction, while the other is

oriented in the 3' to 5' direction

- **antisense RNA** small noncoding RNA molecules that inhibit gene expression by binding to mRNA transcripts via complementary base pairing
- **antisense strand** transcription template strand of DNA; the strand that is transcribed for gene expression
- **antiseptis** protocol that removes potential pathogens from living tissue
- **antiseptic** antimicrobial chemical that can be used safely on living tissue
- **antiserum** serum obtained from an animal containing antibodies against a particular antigen that was artificially introduced to the animal
- **apoenzyme** enzyme without its cofactor or coenzyme
- **apoptosis** programmed and organized cell death without lysis of the cell
- **arachnoid mater** middle membrane surrounding the brain that produces cerebrospinal fluid
- **arboviral encephalitis** infection by an arthropod-borne virus that results in an inflammation of the brain
- **arbovirus** any of a variety of viruses that are transmitted by arthropod vectors
- **archaea** any of various unicellular prokaryotic microorganisms, typically having cell walls containing pseudopeptidoglycan
- **Archaea** domain of life separate from the domains Bacteria and Eukarya
- **artemisinin** antiprotozoan and antifungal drug effective against malaria that is thought to increase intracellular levels of reactive oxygen species in target microbes
- **artery** large, thick-walled vessel that carries blood from the heart to the body tissues
- **Arthus reaction** localized type III hypersensitivity
- **artificial active immunity** immunity acquired through exposure to pathogens and pathogen antigens through a method other than natural infection
- **artificial passive immunity** transfer of antibodies produced by a donor to another individual for the purpose of preventing or treating disease

- **ascariasis** soil-transmitted intestinal infection caused by the large nematode roundworm *Ascaris lumbricoides*
- **ascocarps** cup-shaped fruiting bodies of an ascomycete fungus
- **ascospore** asexual spore produced by ascomycete fungi
- **ascus** structure of ascomycete fungi containing spores
- **asepsis** sterile state resulting from proper use of microbial control protocols
- **aseptic technique** method or protocol designed to prevent microbial contamination of sterile objects, locations, or tissues
- **aspergillosis** fungal infection caused by the mold *Aspergillus*; immunocompromised patients are primarily at risk
- **asymptomatic carrier** an infected individual who exhibits no signs or symptoms of disease yet is capable of transmitting the pathogen to others
- **asymptomatic** not exhibiting any symptoms of disease
- **atomic force microscope** a scanning probe microscope that uses a thin probe that is passed just above the specimen to measure forces between the atoms and the probe
- **ATP synthase** integral membrane protein that harnesses the energy of the proton motive force by allowing hydrogen ions to diffuse down their electrochemical gradient, causing components of this protein to spin, making ATP from ADP and P_i
- **attachment** binding of phage or virus to host cell receptors
- **attenuation** regulatory system of prokaryotes whereby secondary stem-loop structures formed within the 5' end of an mRNA being transcribed determine both if transcription to complete the synthesis of this mRNA will occur and if this mRNA will be used for translation
- **autoclave** specialized device for the moist-heat sterilization of materials through the application of pressure to steam, allowing the steam to reach temperatures above the boiling point of water
- **autocrine function** refers to a cytokine signal released from a cell to a receptor on its own surface
- **autograft** tissue transplanted from a location on an individual to a different location on the same individual
- **autoimmune disease** loss of tolerance to self, resulting in immune-mediated destruction of self cells and tissues

- **autoinducer** signaling molecule produced by a bacterial cell that can modify the activity of surrounding cells; associated with quorum sensing
- **autoradiography** the method of producing a photographic image from radioactive decay; in molecular genetics the method allows the visualization of radioactively-labeled DNA probes that have hybridized to a nucleic acid sample
- **autotroph** organism that converts inorganic carbon dioxide into organic carbon
- **auxotroph** nutritional mutant with a loss-of-function mutation in a gene encoding the biosynthesis of a specific nutrient such as an amino acid
- **avidity** strength of the sum of the interactions between an antibody and antigen
- **axon** long projection of a neuron along which an electrochemical signal is transmitted
- **azithromycin** semisynthetic macrolide with increased spectrum of activity, decreased toxicity, and increased half-life compared with erythromycin

B

- **β -lactamases** bacterially produced enzymes that cleave the β -lactam ring of susceptible β -lactam antimicrobials, rendering them inactive and conferring resistance
- **β -lactams** group of antimicrobials that inhibit cell wall synthesis; includes the penicillins, cephalosporins, carbapenems, and monobactams; inhibits the transpeptidase cross-linking activity of penicillin-binding proteins
- **β -oxidation** process of fatty acid degradation that sequentially removes two-carbon acetyl groups, producing NADH and FADH₂, on entry into the Krebs cycle
- **β -pleated sheet** secondary structure consisting of pleats formed by hydrogen bonds between localized segments of amino acid residues on the backbone of the polypeptide chain

- **B-cell receptors (BCRs)** membrane-bound IgD and IgM antibody that bind specific antigen epitopes with Fab antigen-binding region
- **B lymphocyte** antibody-producing cells of humoral immunity; B cell
- **babesiosis** tickborne protozoan infection caused by *Babesia* spp. and characterized by malaise, fatigue, fever, headache, myalgia, and joint pain
- **bacillary dysentery** gastrointestinal illness caused by *Shigella* bacteria, also called shigellosis
- **bacillus** (bacilli) rod-shaped prokaryotic cell
- **bacitracin** group of structurally similar peptides that block the movement of peptidoglycan precursors across the cell membrane, inhibiting peptidoglycan synthesis
- **bacteremia** condition marked by the presence of bacteria in the blood
- **bacteria** (singular: bacterium) any of various unicellular prokaryotic microorganisms typically (but not always) having cell walls that contain peptidoglycan
- **bacterial lawn** layer of confluent bacterial growth on an agar plate
- **bacterial meningitis** bacterial infection that results in an inflammation of the meninges
- **bacterial vaginosis** a condition caused by an overgrowth of bacteria in the vagina that may or may not cause symptoms
- **bactericidal** irreversible inhibition of a microbe's ability to divide
- **bactericide** chemical or physical treatment that kills bacteria
- **bacteriochlorophylls** green, purple, or blue pigments of bacteria; they are similar to chlorophyll of plants
- **bacteriology** the study of bacteria
- **bacteriophage** virus that infects bacteria
- **bacteriostatic** having the ability to inhibit bacterial growth, generally by means of chemical or physical treatment; reversible inhibition of a microbe's ability to divide
- **barophile** organism that grows under high atmospheric pressure
- **basal body** component of eukaryotic flagellum or cilium composed of nine microtubule triplets and attaches the flagellum or cilium to the cell
- **base sequence** identity of the specific nucleotides present in a nucleic acid strand and their order within the strand

- **basic dye** a chromophore with a positive charge that attaches to negatively charged structures
- **basidia (basidium, sing.)** small club-shaped structures of basidiomycete fungi where basidiospores are produced
- **basidiocarps** fruiting bodies of basidiomycete fungi
- **basidiospores** spores produced sexually via budding in basidiomycete fungi
- **basophils** leukocytes with granules containing histamine and other chemicals that facilitate allergic responses and inflammation when released
- **benzimidazoles** class of antihelminthic drugs that bind to helminthic β -tubulin, preventing microtubule formation
- **Betaproteobacteria** class of Proteobacteria that are all eutrophs
- **binary fission** predominant form of bacterial reproduction in which one cell divides into two daughter cells of equal size, which separate, each offspring receiving a complete copy of the parental genome
- **binocular** having two eyepieces
- **binomial nomenclature** a universal convention for the scientific naming of organisms using Latinized names for genus and species
- **biofilm** complex ecosystem of bacteria embedded in a matrix
- **biogeochemical cycle** recycling of inorganic matter between living organisms and their nonliving environment
- **bioinformatics** the analysis of large amounts of information required for interpretation of these data
- **biological transmission** movement of a pathogen between hosts facilitated by a biological vector in which the pathogen grows and reproduces
- **biological vector** an animal (typically an arthropod) that is infected with a pathogen and is capable of transmitting the pathogen from one host to another
- **biomarker** a protein expressed by a cell or tissue that is indicative of disease
- **biomolecule** a molecule that is part of living matter
- **bioremediation** use of microbes to remove xenobiotics or environmental pollutants from a contaminated site
- **biosynthesis** replication of viral genome and other protein components

- **biotechnology** the science of using living systems to benefit humankind
- **bisbiguanide** type of chemical compound with antiseptic properties; disrupts cell membranes at low concentrations and causes congealing of intracellular contents at high concentrations
- **blastomycosis** fungal disease associated with infections by *Blastomyces dermatitidis*; can cause disfiguring scarring of the hands and other extremities
- **blepharitis** inflammation of the eyelids
- **blocking antibodies** antigen-specific antibodies (usually of the IgG type) produced via desensitization therapy
- **blood-brain barrier** tight cell junctions of the endothelia lining the blood vessels that serve the central nervous system, preventing passage of microbes from the bloodstream into the brain and cerebrospinal fluid
- **blue-white screening** a technique commonly used for identifying transformed bacterial cells containing recombinant plasmids using *lacZ*-encoding plasmid vectors
- **blunt ends** ends of DNA molecules lacking single-stranded complementary overhangs that are produced when some restriction enzymes cut DNA
- **botulism** form of flaccid paralysis caused by the ingestion of a neurotoxin produced by *Clostridium botulinum*
- **bradykinin** activated form of a proinflammatory molecule induced in the presence of invader microbes; opens gaps between cells in blood vessels, allowing fluid and cells to leak into surrounding tissue
- **bridge reaction** reaction linking glycolysis to the Krebs cycle during which each pyruvate is decarboxylated and oxidized (forming NADH), and the resulting two-carbon acetyl group is attached to a large carrier called coenzyme A, resulting in the formation of acetyl-CoA and CO₂; also called the *transition reaction*
- **brightfield microscope** a compound light microscope with two lenses; it produces a dark image on a bright background
- **broad-spectrum antimicrobial** drug that targets many different types of microbes
- **bronchi** major air passages leading to the lungs after bifurcating at the windpipe

- **bronchioles** smaller air passages within the lung that are formed as the bronchi become further subdivided
- **bronchitis** inflammation of the bronchi
- **brucellosis** zoonotic disease caused by bacteria of the genus *Brucella* that results in undulant fever
- **bubo** swollen, inflamed lymph node that forms as a result of a microbial infection
- **bubonic plague** most common form of plague in humans, marked by the presence of swollen lymph nodes (buboes)
- **budding** unequal reproductive division in which a smaller cell detaches from the parent cell
- **budding yeasts** yeasts that divide by budding off of daughter cells
- **Burkitt lymphoma** disease characterized by rapidly growing solid tumor; caused by Epstein-Barr virus (HHV-4)
- **burst** release of new virions by a lysed host cell infected by a virus
- **burst size** the number of virions released from a host cell when it is lysed because of a viral infection

C

- **Calvin-Benson cycle** most common CO₂ fixation pathway in most photoautotrophs; involves light-independent reactions of photosynthesis that occur in the cytoplasm of photosynthetic bacteria and in the stroma of eukaryotic chloroplasts
- ***Campylobacter jejuni* gastroenteritis** gastroenteritis caused by *C. jejuni*; generally mild but sometimes with serious complications
- **candidiasis** fungal infection caused by *Candida* spp., especially *C. albicans*; can affect various regions of the body, e.g., skin (cutaneous candidiasis), oral cavity (oral thrush), or vagina (yeast infection)
- **candle jar** container with a tight-fitting lid in which a burning candle consumes oxygen and releases carbon dioxide, thereby creating an environment suitable for capnophiles
- **capillary** small blood vessel found in the interstitial space of tissue; delivers nutrients and oxygen, and removes waste products
- **capnophile** organism that requires carbon dioxide levels higher than atmospheric concentration

- **capsid** protein coat surrounding the genome of the virus
- **capsomere** individual protein subunits that make up the capsid
- **capsule staining** a negative staining technique that stains around a bacterial capsule while leaving the capsule clear
- **capsule** type of glycocalyx with organized layers of polysaccharides that aid in bacterial adherence to surfaces and in evading destruction by immune cells
- **carbapenem-resistant Enterobacteriaceae (CRE)** group of bacteria that have developed resistance to all β -lactams, including carbapenems, and many other drug classes
- **carbohydrate** the most abundant type of biomolecule, consisting of carbon, hydrogen, and oxygen
- **carbon skeleton** chain of carbon atoms to which one or more functional groups are bound
- **carboxysome** an inclusion composed of an outer shell of thousands of protein subunits. Its interior is filled with ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) and carbonic anhydrase, which are both used for carbon metabolism
- **carbuncle** abscess containing a large, deep, purulent skin lesion
- **carcinogen** agent that causes cancer
- **case-control study** a type of observational study in which a group of affected individuals are compared, usually retrospectively, to a similar group of unaffected individuals
- **catabolic activator protein (CAP)/cAMP receptor protein (CRP)** protein that, when bound to cAMP in the presence of low levels of glucose, binds to the promoters of operons that control the processing of alternative sugars
- **catabolism** chemical reactions that break down complex molecules into simpler ones
- **catabolite repression** repression of the transcription of operons encoding enzymes for the use of substrates other than glucose when glucose levels are high
- **catalase** enzyme that breaks down hydrogen peroxide to water and oxygen
- **catalyst** molecule that increases the rate of a chemical reaction but is not used or changed during the chemical reaction and, thus, is reusable

- **catarrhal stage** in pertussis, a disease stage marked by inflammation of the mucous membranes combined with excessive secretions
- **cat-scratch disease** bacterial infection of the lymph nodes caused by *Bartonella henselae*; frequently transmitted via a cat scratch
- **causative agent** the pathogen or substance responsible for causing a particular disease; etiologic agent
- **CCA amino acid binding end** region of a mature tRNA that binds to an amino acid
- **celiac disease** disease largely of the small intestine caused by an immune response to gluten that results in the production of autoantibodies and an inflammatory response
- **cell envelope** the combination of external cellular structures (e.g., plasma membrane, cell wall, outer membrane, glycocalyxes) that collectively contain the cytoplasm and internal structures of a cell
- **cell membrane** lipid bilayer with embedded proteins and carbohydrates that defines the boundary of the cell (also called the cytoplasmic membrane or plasma membrane)
- **cell morphology** cell shape, structure, and arrangement, as viewed microscopically
- **cell theory** the theory that all organisms are composed of cells and that the cell is the fundamental unit of life
- **cell wall** a structure in the cell envelope of some cells that helps the cell maintain its shape and withstand changes in osmotic pressure
- **cellular immunity** adaptive immunity involving T cells and the destruction of pathogens and infected cells
- **cellulitis** a subcutaneous skin infection that develops in the dermis or hypodermis, resulting in a red, painful inflammation
- **cellulose** a structural polysaccharide composed of glucose monomers linked together in a linear chain by glycosidic bonds
- **Centers for Disease Control and Prevention (CDC)** the national public health agency in the United States
- **central dogma** scientific principle explaining the flow of genetic information from DNA to RNA to protein
- **central nervous system (CNS)** portion of the nervous system made up of the brain and spinal cord
- **central tolerance** negative selection of self-reactive T cells in thymus

- **centriole** a component of a centrosome with the structural array of nine parallel microtubules arranged in triplets; involved in eukaryotic cell division
- **centrosome** a microtubule-organizing center for the mitotic spindle found in animal cells; it separates chromosomes during cell division and is composed of a pair of centrioles positioned at right angles to each other
- **cephalosporins** a group of cell wall synthesis inhibitors within the class of β -lactams
- **cercarial dermatitis** inflammation of the skin caused by a reaction to cercaria of *Schistosoma* spp., which can penetrate the skin and blood vessels; also called swimmer's itch or clam digger's itch
- **cerebrospinal fluid (CSF)** sterile liquid produced in the brain that fills the subarachnoid space of the brain and spinal column
- **cervix** the part of the uterus that connects to the vagina
- **CFB group** phylum consisting of the gram-negative, rod-shaped nonproteobacteria genera *Cytophaga*, *Fusobacterium*, and *Bacteroides*
- **Chagas disease** potentially fatal protozoan infection caused by *Trypanosoma cruzi* and endemic to Central and South America; transmitted by the triatomine bug (kissing bug)
- **chancroid** an STI caused by *Haemophilus ducreyi* that produces soft chancres on genitals
- **charged tRNA** activated tRNA molecule carrying its cognate amino acid
- **chemical mediators** chemicals or enzymes produced by a variety of cells; provide nonspecific antimicrobial defense mechanisms
- **chemically defined media** media in which all components are chemically defined
- **chemiosmosis** flow of hydrogen ions across the membrane through ATP synthase
- **chemokines** chemotactic cytokines that recruit specific subsets of leukocytes to infections, damaged tissue, and sites of inflammation
- **chemotaxis** directional movement of a cell in response to a chemical attractant
- **chemotroph** organism that gets its energy from the transfer of electrons originating from chemical compounds

- **chickenpox** common childhood disease caused by the varicella-zoster virus and marked by the formation of pustular lesions on the trunk
- **chikungunya fever** mosquito-borne viral disease caused by the chikungunya virus and characterized by high fever, joint pain, rash, and blisters
- **chirality** property of stereoisomer molecules by which their structures are nonsuperimposable mirror-images
- **chitin** polysaccharide that is an important component of fungal cell walls
- **chlamydia** a common STI caused by *Chlamydia trachomatis*
- **chloramphenicol** protein synthesis inhibitor with broad-spectrum activity that binds to the 50S subunit, inhibiting peptide bond formation
- **chlorophyll** a type of photosynthetic pigment found in some prokaryotic and eukaryotic cells
- **chloroplast** organelle found in plant and algal cells in which photosynthesis occurs
- **cholera** gastrointestinal illness caused by *Vibrio cholera* characterized by severe diarrhea
- **chromatin** combination of DNA with DNA binding proteins
- **chromogenic substrate** colorless substrate (chromogen) that is converted into a colored end product by the enzyme
- **chromophores** pigments that absorb and reflect particular wavelengths of light (giving them a color)
- **chromosome** discrete DNA structure within a cell that controls cellular activities
- **chronic disease** any disease that progresses and persists over a long time
- **chronic granulomatous disease** primary immunodeficiency caused by an impaired ability of phagocytic cells to kill ingested bacteria in the phagolysosome
- **chronic wasting disease** prion disease of deer and elk in the United States and Canada
- **cilia (singular: cilium)** short filamentous structures found on some eukaryotic cells; each is composed of microtubules in a 9+2 array, and may be used for locomotion, feeding, and/or movement of extracellular particles that come in contact with the cell

- **ciliated epithelial cells** hair-like cells in the respiratory tract that beat, pushing mucus secretions and trapped debris away from the sensitive tissues of the lungs
- **ciliates** protists with cilia (Ciliophora), including *Paramecium* and *Stentor*, classified within the Chromalveolata
- **cisternae** the sacs of the endoplasmic reticulum
- **citric acid cycle** see *Krebs cycle*
- **class switching** genetic rearrangement of constant region gene segments in plasma cells to switch antibody production from IgM to IgG, IgA, or IgE
- **clindamycin** semisynthetic protein synthesis inhibitor of the lincosamide class that binds to the 50S subunit, inhibiting peptide bond formation
- **clone** a genetically identical cell or individual
- ***Clostridium perfringens* gastroenteritis** relatively mild gastrointestinal illness caused by *C. perfringens*
- **clusters of differentiation (CD)** cell-surface glycoproteins that serve to identify and distinguish white blood cells
- **coagulase** enzyme that causes the activation of fibrinogen to form fibrin, promoting clotting of the blood
- **coarse focusing knob** a knob on a microscope that produces relatively large movements to adjust focus
- **coccidioidomycosis** disease caused by the highly infectious fungal pathogen *Coccidioides immitis* and related species
- **codon** three-nucleotide sequence within mRNA that specifies a particular amino acid to be incorporated into the polypeptide being synthesized
- **coenocyte** multinucleated eukaryotic cell that forms as a result of multiple rounds of nuclear division without the accompanying division of the plasma membrane
- **coenocytic hyphae** nonseptate hyphae that are multinucleate and lack cell walls or membranes between cells; characteristic of some fungi
- **coenzyme** organic molecule required for proper enzyme function that is not consumed and is reusable
- **cofactor** inorganic ion that helps stabilize enzyme conformation and function

- **cognate amino acid** amino acid added to a specific tRNA molecule that correctly corresponds to the tRNA's anticodon and, hence, the mRNA's codon, reflecting the genetic code
- **cohort method** a method used in observational studies in which a group of individuals is followed over time and factors potentially important in the development of disease are evaluated
- **colistin** membrane-active polymyxin that was historically used for bowel decontamination but now used for systemic infections with drug-resistant pathogens
- **colitis** inflammation of the large intestine
- **collagenase** enzyme that digests collagen, the dominant protein in connective tissue
- **colony-forming unit (CFU)** a counting quantity represented by a colony formed on solid medium from a single cell or a few cells
- **commensalism** type of symbiosis in which one population benefits and the other is not affected
- **commercial sterilization** type of sterilization protocol used in food production; uses conditions that are less harsh (lower temperatures) to preserve food quality but still effectively destroy vegetative cells and endospores of common foodborne pathogens such as *Clostridium botulinum*
- **common cold** most common cause of rhinitis in humans; associated with a variety of adenoviruses, coronaviruses, and rhinoviruses
- **common source spread** a mode of disease transmission in which every infection originates from the same source
- **communicable** able to be transmitted directly or indirectly from one person to another
- **community** group of interacting populations of organisms
- **competitive inhibitor** molecule that binds to an enzyme's active site, preventing substrate binding
- **competitive interactions** interactions between populations in which one of them competes with another for resources
- **complement activation** cascading activation of the complement proteins in the blood, resulting in opsonization, inflammation, and lysis of pathogens
- **complement fixation test** test for antibodies against a specific pathogen using complement-mediated hemolysis

- **complement system** series of proteins that can become activated in the presence of invading microbes, resulting in opsonization, inflammation, and lysis of pathogens
- **complementary base pairs** base pairing due to hydrogen bonding that occurs between a specific purine and a specific pyrimidine; A bonds with T (in DNA), and C bonds with G
- **complementary DNA (cDNA)** a DNA molecule complementary to mRNA that is made through the activity of reverse transcriptase
- **complex media** media that contain extracts of animals and plants that are not chemically defined
- **complex virus** virus shape that often includes intricate characteristics not seen in the other categories of capsid
- **compound microscope** a microscope that uses multiple lenses to focus light from the specimen
- **condenser lens** a lens on a microscope that focuses light from the light source onto the specimen
- **conditional mutation** mutant form of a gene whose mutant phenotype is expressed only under certain environmental conditions
- **confocal microscope** a scanning laser microscope that uses fluorescent dyes and excitation lasers to create three-dimensional images
- **conidia** asexual fungal spores not enclosed in a sac; produced in a chain at the end of specialized hyphae called conidiophores
- **conjugate vaccine** a vaccine consisting of a polysaccharide antigen conjugated to a protein to enhance immune response to the polysaccharide; conjugate vaccines are important for young children who do not respond well to polysaccharide antigens
- **conjugated protein** protein carrying a nonpolypeptidic portion
- **conjugation** mechanism of horizontal gene transfer in bacteria in which DNA is directly transferred from one bacterial cell to another by a conjugation pilus
- **conjugation pilus (sex pilus)** hollow tube composed of protein encoded by the conjugation plasmid that brings two bacterial cells into contact with each other for the process of conjugation
- **conjunctiva** the mucous membranes covering the eyeball and inner eyelid
- **conjunctivitis** inflammation of the conjunctiva, the mucous membrane covering the eye and inside of the eyelid

- **constitutively expressed** describes genes that are transcribed and translated continuously to provide the cell with constant intermediate levels of the protein products
- **contact dermatitis** inflammation of the skin resulting from a type IV hypersensitivity to an allergen or irritant
- **contact** see *exposure*
- **contact transmission** movement of a pathogen between hosts due to contact between the two; may be direct or indirect
- **contagious** easily spread from person to person
- **continuous cell line** derived from transformed cells or tumors, these cells are often able to be subcultured many times, or, in the case of immortal cell lines, grown indefinitely
- **continuous common source spread** a mode of disease transmission in which every infection originates from the same source and that source produces infections for longer than one incubation period
- **contractile vacuoles** organelles found in some cells, especially in some protists, that take up water and then move the water out of the cell for osmoregulatory purposes (i.e., to maintain an appropriate salt and water balance)
- **contrast** visible differences between parts of a microscopic specimen
- **convalescence stage** the final stage of a whooping cough infection, marked by a chronic cough
- **Coombs' reagent** antiserum containing antihuman immunoglobulins used to facilitate hemagglutination by cross-linking the human antibodies attached to red blood cells
- **cooperative interactions** interactions between populations in which both benefit
- **cortex** tightly packed layer of fungal filaments at the outer surface of a lichen; foliose lichens have a second cortex layer beneath the medulla
- **counterstain** a secondary stain that adds contrasting color to cells from which the primary stain has been washed out by a decolorizing agent
- **crenation** shriveling of a cell
- **Creutzfeldt-Jakob disease** form of transmissible spongiform encephalopathy found in humans; typically a fatal disease
- **crisis phase** point at which a fever breaks, reaching a peak before the hypothalamus resets back to normal body temperature

- **critical item** object that must be sterile because it will be used inside the body, often penetrating sterile tissues or the bloodstream
- **cross-match** in the major cross-match, donor red blood cells are checked for agglutination using recipient serum; in the minor cross-match, donor serum is checked for agglutinating antibodies against recipient red blood cells
- **cross-presentation** a mechanism by which dendritic cells process antigens for MHC I presentation to CD8 T cells through phagocytosis of the pathogen (which would normally lead to MHC II presentation)
- **cross-resistance** when a single resistance mechanism confers resistance to multiple antimicrobial drugs
- **cross-sectional study** a type of observational study in which measurements are made on cases, both affected and unaffected, at one point in time and the measurements analyzed to uncover associations with the disease state
- **crustose lichens** lichens that are tightly attached to the substrate, giving them a crusty appearance
- **cryptococcosis** fungal pneumonia caused by the encapsulated yeast *Cryptococcus neoformans* commonly found in bird droppings
- **cryptosporidiosis** intestinal infection caused by *Cryptosporidium parvum* or *C. hominis*
- **culture density** the number of cells per volume of broth
- **culture medium** combination of compounds in solution that supports growth
- **cutaneous mycosis** any fungal infection that affects the surface of the skin, hair, or nails
- **cyanobacteria** phototrophic, chlorophyll-containing bacteria that produce large amounts of gaseous oxygen
- **cyclic AMP (cAMP)** intracellular signaling molecule made through the action of adenylyl cyclase from ATP when glucose levels are low, with the ability to bind to a catabolite activator protein to allow it to bind to regulatory regions and activate the transcription of operons encoding enzymes for metabolism of alternative substrates
- **cyclic photophosphorylation** pathway used in photosynthetic organisms when the cell's need for ATP outweighs that for NADPH, thus bypassing NADPH production
- **cyclosporiasis** intestinal infection caused by *Cyclospora cayetanensis*

- **cystic echinococcosis** hydatid disease, an infection caused by the tapeworm *Echinococcus granulosus* that can cause cyst formation
- **cysticerci** larval form of a tapeworm
- **cystitis** inflammation of the bladder
- **cysts** microbial cells surrounded by a protective outer covering; some microbial cysts are formed to help the microbe survive harsh conditions, whereas others are a normal part of the life cycle
- **cytochrome oxidase** final ETS complex used in aerobic respiration that transfers energy-depleted electrons to oxygen to form H₂O
- **cytokine storm** an excessive release of cytokines, typically triggered by a superantigen, that results in unregulated activation of T cells
- **cytokines** protein molecules that act as a chemical signals; produced by cells in response to a stimulation event
- **cytomegalovirus (CMV) infection** human herpesvirus 5 infection that is typically asymptomatic but can become serious in immunocompromised patients, transplant recipients, and developing fetuses
- **cytopathic effect** cell abnormality resulting from a viral infection
- **cytoplasm** the gel-like material composed of water and dissolved or suspended chemicals contained within the plasma membrane of a cell
- **cytoplasmic membrane** see *cell membrane*
- **cytoproct** a protozoan cell structure that is specialized for excretion
- **cytosine** pyrimidine nitrogenous base found in nucleotides
- **cytoskeleton** a network of filaments or tubules in the eukaryotic cell that provides shape and structural support for cells; aids movement of materials throughout the cell
- **cytostome** a protozoan cell structure that is specialized for phagocytosis (i.e., to take in food)
- **cytotoxic T cells** effector cells of cellular immunity that target and eliminate cells infected with intracellular pathogens through induction of apoptosis
- **cytotoxicity** harmful effects to host cell

- **dacryocystitis** inflammation of the lacrimal sac often associated with a plugged nasolacrimal duct
- **daptomycin** cyclic lipopeptide that disrupts the bacterial cell membrane
- **darkfield microscope** a compound light microscope that produces a bright image on a dark background; typically a modified brightfield microscope
- **death phase (decline phase)** phase of the growth curve at which the number of dying cells exceeds the number of new cells formed
- **decimal reduction time (DRT) or D-value** amount of time it takes for a specific protocol to produce a one order of magnitude decrease in the number of organisms; that is, death of 90% of the population
- **decolorizing agent** a substance that removes a stain, usually from some parts of the specimen
- **deeply branching bacteria** bacteria that occupy the lowest branches of the phylogenetic tree of life
- **definitive host** the preferred host organism for a parasite, in which the parasite reaches maturity and may reproduce sexually
- **degeneracy** redundancy in the genetic code because a given amino acid is encoded by more than one nucleotide triplet codon
- **degerming** protocol that significantly reduces microbial numbers by using mild chemicals (e.g., soap) and gentle scrubbing of a small area of skin or tissue to avoid the transmission of pathogenic microbes
- **degranulation** release of the contents of mast cell granules in response to the cross-linking of IgE molecules on the cell surface with allergen molecules
- **dehydration synthesis** chemical reaction in which monomer molecules bind end to end in a process that results in the formation of water molecules as a byproduct
- **deletion** type of mutation involving the removal of one or more bases from a DNA sequence
- **Deltaproteobacteria** class of Proteobacteria that includes sulfate-reducing bacteria
- **denatured protein** protein that has lost its secondary and tertiary structures (and quaternary structure, if applicable) without the loss of its primary structure
- **dendrites** branched extensions of the soma of a neuron that interact with other cells

- **dengue fever** mosquito-borne viral hemorrhagic disease; also known as breakbone fever
- **dental calculus** calcified heavy plaque on teeth, also called tartar
- **dental caries** cavities formed in the teeth as a result of tooth decay caused by microbial activity
- **deoxyribonucleic acid (DNA)** double-stranded nucleic acid composed of deoxyribonucleotides that serves as the genetic material of the cell
- **deoxyribonucleotides** DNA nucleotides containing deoxyribose as the pentose sugar component
- **dermatophyte** any fungus of the genera *Microsporum*, *Epidermophyton*, or *Trichophyton*, which feed on keratin (a protein found in skin, hair, and nails) and can cause cutaneous infections
- **dermis** the second layer of human skin, found between the epidermis and the hypodermis
- **descriptive epidemiology** a method of studying a disease outbreak using case histories, contact interviews, medical information, and other sources of information
- **desensitization** injections of antigen that lead to production of antigen-specific IgG molecules, effectively outcompeting IgE molecules on the surface of sensitized mast cells for antigen
- **desiccation** method of microbial control involving the removal of water from cells through drying or dehydration
- **desquamation** peeling and shedding of outermost skin
- **diapedesis** process by which leukocytes pass through capillary walls to reach infected tissue; also called extravasation
- **diaphragm** a component of a microscope; typically consists of a disk under the stage with holes of various sizes; can be adjusted to allow more or less light from the light source to reach the specimen
- **differential interference-contrast microscope** a microscope that uses polarized light to increase contrast
- **differential media** media that contain additives that make it possible to distinguish bacterial colonies based on metabolic activities of the organisms
- **differential staining** staining that uses multiple dyes to differentiate between structures or organisms
- **diffraction** the changing of direction (bending or spreading) that occurs when a light wave interacts with an opening or barrier

- **dikaryotic** having two separate nuclei within one cell
- **dimorphic fungus** a fungus that can take the form of a yeast or a mold, depending on environmental conditions
- **dioecious** refers to sexually reproducing organisms in which individuals have either male or female reproductive organs (not both)
- **diphtheria** serious infection of the larynx, caused by the toxigenic bacterium *Corynebacterium diphtheriae*
- **diploid** having two copies of each chromosome
- **direct agglutination assay** assay that can be used to detect the agglutination of bacteria by the action of antibodies in patient serum
- **direct antihuman globulin test (DAT)** another name for a direct Coombs' test
- **direct contact transmission** movement of a pathogen between hosts by physical contact or transfer in droplets at a distance less than one meter
- **direct Coombs' test** assay that looks for antibodies *in vivo* against red blood cells caused by various types of infections, drug reactions, and autoimmune disorders
- **direct ELISA** enzyme-linked immunoabsorbent assay in which the antigens are immobilized in the well of a microtiter plate; only a single antibody is used in the test
- **direct fluorescent antibody (DFA) test** FA technique in which the labeled antibody binds to the target antigen
- **direct hemagglutination assay** test that determines the titer of certain bacteria and viruses that causes clumping of red blood cells
- **direct microscopic cell count** counting of cells using a calibrated slide under a light microscope
- **direct repair (light repair or photoreactivation)** light-dependent mechanism for repairing pyrimidine dimers involving the enzyme photolyase
- **disaccharide** one of two monosaccharides linked together by a glycosidic bond
- **disease** any condition in which the normal structure or function of the body is damaged or impaired
- **disinfectant** antimicrobial chemical applied to a fomite during disinfection that may be toxic to tissues
- **disinfection** protocol that removes potential pathogens from a fomite

- **disk-diffusion method** a technique for measuring of the effectiveness of one or more antimicrobial agents against a known bacterium; involves measuring the zone(s) of inhibition around the chemical agent(s) in a culture of the bacterium
- **dispersion** the separation of light of different frequencies due to different degrees of refraction
- **disulfide bridge** covalent bond between the sulfur atoms of two sulfhydryl side chains
- **DNA gyrase (topoisomerase II)** bacterial topoisomerase that relaxes the supercoiled chromosome to make DNA more accessible for the initiation of replication
- **DNA ligase** enzyme that catalyzes the formation of a covalent phosphodiester linkage between the 3'-OH end of one DNA fragment and the 5' phosphate end of another DNA fragment
- **DNA packaging** process in which histones or other DNA binding proteins perform various levels of DNA wrapping and attachment to scaffolding proteins to allow the DNA to fit inside a cell
- **DNA polymerase** class of enzymes that adds nucleotides to the free 3'-OH group of a growing DNA chain that are complementary to the template strand
- **DNA primers** short, synthetic, single-stranded DNA fragments of known sequence that bind to specific target sequences within a sample due to complementarity between the target DNA sequence and the primer; commonly used in PCR but may be used in other hybridization techniques
- **DNA probe** a single-stranded DNA fragment that is complementary to part of the gene (DNA or RNA) of interest
- **DNase** pathogen-produced nuclease that degrades extracellular DNA
- **dosage** amount of medication given during a certain time interval
- **double immunodiffusion** see Ouchterlony assay
- **doubling time** the time it takes for the population to double; also referred to as generation time
- **droplet transmission** direct contact transmission of a pathogen transferred in sneezed or coughed droplets of mucus that land on the new host within a radius of one meter
- **drug resistance** ability of a microbe to persist and grow in the presence of an antimicrobial drug

- **dry-heat sterilization** protocol that involves the direct application of high heat
- **dura mater** tough, outermost membrane that surrounds the brain
- **dynein** motor proteins that interact with microtubules in eukaryotic flagella and cilia
- **dysentery** intestinal inflammation that causes diarrhea with blood and mucus
- **dysuria** urination accompanied by burning, discomfort, or pain

E

- **E (exit) site** functional site of an intact ribosome that releases dissociated uncharged tRNAs so that they can be recharged with free amino acids
- **East African trypanosomiasis** acute form of African trypanosomiasis caused by *Trypanosoma brucei rhodesiense*
- **eastern equine encephalitis** serious, but rare, mosquito-borne viral infection of the brain that is found primarily on the Atlantic and Gulf coast states of the United States
- **Ebola virus disease (EVD)** potentially fatal viral hemorrhagic fever found primarily in western Africa and transmitted through contact with body fluids
- **eclipse phase** period after viral infection during which the infective virus is not detected, either intracellularly or extracellularly, and biosynthesis is occurring
- **ectoplasm** outer, more gelatinous layer of cytoplasm under a protist cell membrane
- **edema** swelling due to accumulation of fluid and protein in tissue as a result of increased permeability of capillary walls during an inflammatory response; chronic edema can also result from blockage of lymphatic vessels, as in the case of elephantiasis
- **effector cells** activated cells of cellular immunity that are involved in the immediate immune response, primarily to defend the body against pathogens
- **electron carrier** cellular molecule that accepts high-energy electrons from reduced molecules like foods and later serves as an electron

donor in subsequent redox reactions

- **electron microscope** a type of microscope that uses short-wavelength electron beams rather than light to increase magnification and resolution
- **electron transport system (ETS)** series of membrane-associated protein complexes and associated mobile accessory electron carriers important in the generation of the proton motive force required for ATP production by chemiosmosis; the last component involved in the cellular respiration of glucose
- **electroporation** a genetic engineering technique in which cells are exposed to a short electric pulse, inducing them to take up DNA molecules from their environment
- **elementary bodies** metabolically and reproductively inactive, endospore-like form of intracellular bacteria that spreads infection outside of cells
- **elongation in DNA replication** stage of DNA replication during which DNA polymerase adds nucleotides, complementary to the parental strand, to the 3' end of a growing DNA strand
- **elongation in transcription** stage of transcription during which RNA polymerase extends the RNA molecule by adding RNA nucleotides, complementary to the template DNA strand
- **elongation of translation** stage of translation during which amino acids are added one by one to the C-terminus of the growing polypeptide
- **Embden-Meyerhof-Parnas (EMP) pathway** type of glycolysis found in animals and the most common in microbes
- **emerging infectious disease** a disease that is new to the human population or has increased in prevalence over the previous 20 years
- **enantiomers** stereoisomers that are mirror images of each other and nonsuperimposable
- **encephalitis** inflammation of the tissues of the brain
- **encystment** the process of forming a cyst
- **endemic disease** an illness that is constantly present (often at low levels) in a population
- **endergonic reaction** chemical reaction that requires energy beyond activation energy to occur

- **endocarditis** inflammation of the endocardium, especially the heart valves
- **endocrine function** refers to a cytokine signal released from a cell and carried by the bloodstream to a distant recipient cell
- **endocytosis** the uptake of molecules through plasma membrane invagination and vacuole/vesicle formation
- **endomembrane system** a series of organelles (endoplasmic reticulum, Golgi apparatuses, lysosomes, and transport vesicles) arranged as membranous tubules, sacs, and disks that synthesize many cell components
- **endoplasm** inner, more fluid layer of cytoplasm under a protist cell membrane (inside of the ectoplasm)
- **endoplasmic reticulum** part of the endomembrane system that is an interconnected array of tubules and flattened sacs with a single lipid bilayer that may be either rough or smooth; important in synthesizing proteins and lipids
- **endospore** a cellular structure formed by some bacteria in response to adverse conditions; preserves DNA of the cell in a dormant state until conditions are favorable again
- **endospore staining** a differential staining technique that uses two stains to make bacterial endospores appear distinct from the rest of the cell
- **endosymbiotic theory** the theory that mitochondria and chloroplasts arose as a result of prokaryotic cells establishing a symbiotic relationship within a eukaryotic host
- **endothelia** layer of epithelial cells lining blood vessels, lymphatics, the blood-brain barrier, and some other tissues
- **endotoxin** lipid A component of lipopolysaccharides in the outer membrane of gram-negative bacteria
- **enriched media** media that contain additional essential nutrients to support growth
- **enrichment culture** media providing growth conditions that favor the expansion of an organism present in low numbers
- **enteric** bacteria of the family Enterobacteriaceae, which live in the human intestinal tract
- **enteritis** inflammation of the lining of the intestine

- **enterobiasis** intestinal infection caused by the pinworm *Enterobius vermicularis*
- **enterohemorrhagic *E. coli* (EHEC)** *E. coli* bacteria that cause severe gastrointestinal illness with potential serious complications such as hemolytic uremic syndrome
- **enteroinvasive *E. coli* (EIEC)** *E. coli* bacteria that cause relatively mild gastrointestinal illness
- **enteropathogenic *E. coli* (EPEC)** *E. coli* bacteria that cause serious gastrointestinal illness
- **enterotoxigenic *E. coli* (ETEC)** *E. coli* bacteria that cause a relatively mild illness commonly called traveler's diarrhea
- **enterotoxin** toxin that affects the intestines
- **Entner-Doudoroff (ED) pathway** alternative glycolytic pathway used by some bacteria
- **enveloped virus** a virus formed with a nucleic-acid packed capsid surrounded by a lipid layer
- **enzyme** catalyst for biochemical reactions inside cells
- **enzyme immunoassay (EIA)** type of assay wherein an enzyme is coupled to an antibody; addition of a chromogenic substrate for the antibody allows quantification or identification of the antigen bound by the antibody
- **enzyme-linked immunosorbent assay (ELISA)** specialized form of EIA in which either the primary antibody or the antigen is first attached to a solid surface such as the well of a microtiter plate
- **eosinophils** leukocytes with granules containing histamine and major basic protein; facilitate allergic responses and protection against parasitic protozoa and helminths
- **epidemic disease** an illness with a higher-than-expected incidence in a given period within a given population
- **epidemic typhus** severe and sometimes fatal infection caused by *Rickettsia prowazekii* and transmitted by body lice
- **epidemiology** the study of where and when infectious diseases occur in a population and how they are transmitted and maintained in nature
- **epidermis** the outermost layer of human skin
- **epididymis** coiled tube that collects sperm from the testes and passes it on to the vas deferens

- **epididymitis** inflammation of the epididymis caused by a bacterial infection
- **epigenetic regulation** chemical modification of DNA or associated histones to influence transcription
- **epiglottis** flap of cartilage that covers the larynx during swallowing; diverts food to the esophagus and prevents it from entering the respiratory tract
- **epiglottitis** inflammation of the epiglottis
- **epiphyte** a plant that grows on another plant
- **epitope** smaller exposed region on an antigen that is recognized by B-cell and T-cell receptors and antibodies
- **Epsilonproteobacteria** class of Proteobacteria that are microaerophilic
- **equivalence zone** region where the antibody–antigen ratio produces the greatest amount of precipitin in a precipitin reaction
- **erysipelas** a skin infection, typically caused by *Streptococcus pyogenes*, that presents as a red, large, intensely inflamed patch of skin involving the dermis, usually with clear borders, typically on the legs or face
- **erythema nodosum** a condition that causes inflammation in the subcutaneous fat cells of the hypodermis resulting in red nodules
- **erythema** redness at the site of inflammation, usually due to dilation of blood vessels in the area to help bring in white blood cells
- **erythrocyte** red blood cell
- **erythrogenic toxin** exotoxin produced by some strains of *Streptococcus pyogenes*; activity of the toxin can produce the characteristic rash of scarlet fever
- **erythromycin** protein synthesis inhibitor of the macrolide class that is often used as an alternative to penicillin
- **eschar** a localized mass of dead skin tissue
- **Etest** simple, rapid method for determining MIC, involving commercially available plastic strips that contain a gradient of an antimicrobial and are placed on an agar plate inoculated with a bacterial lawn
- **etiologic agent** the pathogen or substance responsible for causing a particular disease; causative agent
- **etiology** the science of the causes of disease

- **Eukarya** the domain of life that includes all unicellular and multicellular organisms with cells that contain membrane-bound nuclei and organelles
- **eukaryote** an organism made up of one or more cells that contain a membrane-bound nucleus and organelles
- **eukaryotic cell** has a nucleus surrounded by a complex nuclear membrane that contains multiple, rod-shaped chromosomes
- **eustachian tube** small passage between the nasopharynx and the middle ear that allows pressure to equalize across the tympanic membrane
- **eutrophs** microorganisms that require a copious amount of organic nutrients; also called copiotrophs
- **excystment** the process of emerging from a cyst
- **exergonic reaction** chemical reaction that does not require energy beyond activation energy to proceed; releases energy when the reaction occurs
- **exocytosis** the release of the contents of transport vesicles to the cell's exterior by fusion of the transport vesicle's membrane with the plasma membrane
- **exoenzyme** secreted enzyme that enhances the ability of microorganisms to invade host cells
- **exon** protein-coding sequence of a eukaryotic gene that is transcribed into RNA and spliced together to code for a polypeptide
- **exonuclease** enzymatic activity that removes RNA primers in DNA introduced by primase
- **exotoxin** biologically active product that causes adverse changes in the host cells
- **experimental epidemiology** the use of laboratory and clinical studies to directly study disease in a population
- **experimental study** a type of scientific study that involves manipulation of the study subjects by the researcher through application of specific treatments hypothesized to affect the outcome while maintaining rigorously controlled conditions
- **exposure** contact between potential pathogen and host; also called contamination or contact
- **extended-spectrum β -lactamases (ESBLs)** β -lactamases carried by some gram-negative bacteria that provide resistance to all penicillins,

cephalosporins, monobactams, and β -lactamase-inhibitor combinations, but not carbapenems

- **extensively drug resistant *Mycobacterium tuberculosis* (XDR-TB)** strains of *M. tuberculosis* that are resistant to rifampin and isoniazid, and also are resistant to any fluoroquinolone and at least one of three other drugs (amikacin, kanamycin, or capreomycin)
- **extracellular matrix** material composed of proteoglycans and fibrous proteins secreted by some eukaryotic cells that lack cell walls; helps multicellular structures withstand physical stresses and coordinates signaling from the external surface of the cell to the interior of the cell
- **extracellular polymeric substances (EPS)** hydrated gel secreted by bacteria in a biofilm containing polysaccharides, proteins, nucleic acids, and some lipids
- **extrachromosomal DNA** additional molecules of DNA distinct from the chromosomes that are also part of the cell's genome
- **extravasation** process by which leukocytes pass through capillary walls to reach infected tissue; also called diapedesis

F

- **F⁻ (recipient) cell** *E. coli* cell lacking the F plasmid and thus incapable of forming a conjugation pilus but capable of receiving the F plasmid during conjugation
- **F pilus (F pili)** specialized type of pilus that aids in DNA transfer between cells; conjugation pilus of *E. coli*
- **F plasmid (fertility factor)** bacterial plasmid in *E. coli* containing genes encoding the ability to conjugate, including genes encoding the formation of the conjugation pilus
- **F' plasmid** integrated F plasmid imprecisely excised from the chromosome; carries with it some chromosomal DNA adjacent to the integration site
- **F⁺ (donor) cell** *E. coli* cell containing the F plasmid, capable of forming a conjugation pilus
- **Fab region** arm of an antibody molecule that includes an antigen-binding site

- **facultative anaerobe** organism that grows better in the presence of oxygen but can proliferate in its absence
- **false negative** negative result to a test for an infection or condition (e.g., presence of antigen, antibody, or nucleic acid) when the infection or condition is actually present
- **false positive** positive result to a test for an infection or condition (e.g., presence of antigen, antibody, or nucleic acid) when the infection or condition is actually absent
- **fastidious organism** organism that has extensive growth requirements
- **fatty acid** lipid that contains long-chain hydrocarbons terminated with a carboxylic acid functional group
- **fatty acid methyl ester (FAME) analysis** technique in which the microbe's fatty acids are extracted, converted to volatile methyl esters, and analyzed by gas chromatography, yielding chromatograms that may be compared to reference data for identification purposes
- **Fc region** region on the trunk of an antibody molecule involved in complement activation and opsonization
- **feedback inhibition** mechanism of regulating metabolic pathway whereby the product of a metabolic pathway noncompetitively binds to an enzyme early on in the pathway, temporarily preventing the synthesis of the product
- **fermentation** process that uses an organic molecule as a final electron acceptor to regenerate NAD^+ from NADH such that glycolysis can continue
- **fever** system-wide sign of inflammation that raises the body temperature and stimulates the immune response
- **fifth disease** a highly contagious illness, more commonly affecting children, marked by a distinctive "slapped-cheek" rash and caused by parvovirus B19
- **fimbriae** filamentous appendages found by the hundreds on some bacterial cells; they aid adherence to host cells
- **fine focusing knob** a knob on a microscope that produces relatively small movements to adjust focus
- **fixation** the process by which cells are killed and attached to a slide
- **flagella** long, rigid, spiral structures used by prokaryotic cells for motility in aqueous environments; composed of a filament made of

flagellin, a hook, and motor (basal body) that are attached to the cell envelope

- **flagella staining** a staining protocol that uses a mordant to coat the flagella with stain until they are thick enough to be seen
- **flagellum (eukaryotic) (plural: flagella)** long, whip-like, filamentous external structure found on some eukaryotic cells; composed of microtubules in a 9+2 arrangement; used for locomotion
- **flavin adenine dinucleotide (FAD/FADH₂)** oxidized/reduced forms of an electron carrier in cells
- **flocculant** visible aggregation that forms between a substance in suspension (e.g., lipid in water) and antibodies against the substance
- **flow cytometry** technique analyzing cells for fluorescence intensity; specific subsets of cells are usually labeled in some way prior to the analysis
- **fluconazole** antifungal drug of the imidazole class that is administered orally or intravenously for the treatment of several types of systemic yeast infections
- **fluid mosaic model** refers to the ability of membrane components to move fluidly within the plane of the membrane, as well as the mosaic-like composition of the components
- **flukes** any of the parasitic nonsegmented flatworms (trematodes) that have an oral sucker and sometimes a second ventral sucker; they attach to the inner walls of intestines, lungs, large blood vessels, or the liver in human hosts
- **fluorescence microscope** a microscope that uses natural fluorochromes or fluorescent stains to increase contrast
- **fluorescence-activated cell sorter (FACS)** technique for using a flow cytometer to physically separate cells into two populations based on fluorescence intensity
- **fluorescent antibody (FA) techniques** suite of assays that use a fluorescently labeled antibody to bind to and so make an antigen easy to visualize
- **fluorescent enzyme immunoassay (FEIA)** EIA in which the substrate is a fluorogen that becomes fluorescent following reaction with the enzyme
- **fluorescent** the ability of certain materials to absorb energy and then immediately release that energy in the form of light

- **fluorochromes** chromophores that fluoresce (absorb and then emit light)
- **fluorogen** nonfluorescent molecule that becomes fluorescent on enzyme or laser activation
- **fluorophore** molecule that fluoresces when excited by light
- **fluoroquinolones** class of synthetic antimicrobials that inhibit the activity of DNA gyrase, preventing DNA replication
- **focal infection** infection in which the pathogen causes infection in one location that then spreads to a secondary location
- **focal length** the distance from the lens to the image point when the object is at a definite distance from the lens (this is also the distance to the focal point)
- **focal point** a property of the lens; the image point when light entering the lens is parallel (i.e., the object is an infinite distance from the lens)
- **foliose lichens** lichens that have lobes that may appear to resemble leaves
- **folliculitis** a skin infection characterized by localized inflammation of hair follicles, typically producing an itchy red rash
- **fomite** inanimate item that may harbor microbes and aid in disease transmission
- **foodborne disease** disease that is transmitted through contaminated food
- **fragmentation** newly formed cells split away from the parent filament in actinomycetes and cyanobacteria
- **frameshift mutation** mutation resulting from either an insertion or a deletion in a number of nucleotides that, if not a multiple of three, changes every amino acid after the mutation
- **free ribosome** eukaryotic 80S ribosome found in the cytoplasm; synthesizes water-soluble proteins
- **frequency** the rate of vibration for a light wave or other electromagnetic wave
- **fruticose lichens** lichens that are generally branched with a rounded appearance
- **functional groups** specific groups of atoms that may occur within a molecule, conferring specific chemical properties
- **fungi** (singular: fungus) any of various unicellular or multicellular eukaryotic organisms, typically having cell walls made out of chitin

- and lacking photosynthetic pigments, vascular tissues, and organs
- **fungicide** chemical or physical treatment that kills fungi
- **fungistatic** having the ability to inhibit fungal growth, generally by means of chemical or physical treatment
- **furuncle** a small, purulent skin lesion; sometimes called a boil
- **fusion inhibitor** antiviral drug that blocks the fusion of HIV receptors to the coreceptors required for virus entry into the cell, specifically, chemokine receptor type 5

G

- **Gammaproteobacteria** class of Proteobacteria that is very diverse and includes a number of human pathogens
- **gas gangrene** rapidly spreading infection of necrotic tissues caused by the gram-positive anaerobe *Clostridium perfringens* and other *Clostridium* spp.
- **gastritis** inflammation of the lining of the stomach
- **gastroenteritis** inflammation of the lining of the stomach and intestine
- **gene expression** production of proteins from the information contained in DNA through the processes of transcription and translation
- **gene gun** an apparatus that shoots gold or tungsten particles coated with recombinant DNA molecules at high speeds into plant protoplasts
- **gene silencing** a genetic engineering technique in which researchers prevent the expression of a particular gene by using small interfering RNAs (siRNAs) or microRNAs (miRNAs) to interfere with translation
- **gene therapy** a form of treatment for diseases that result from genetic mutations; involves the introduction of nonmutated, functional genes into the genome of the patient, often by way of a viral vector
- **generalized transduction** transfer of a random piece of bacterial chromosome DNA by the phage
- **generation time** see *doubling time*
- **genes** segments of DNA molecules that code for proteins or stable RNA molecules
- **genetic code** correspondence between mRNA nucleotide codons and the translated amino acids

- **genetic engineering** the direct alteration of an organism's genetics to achieve desirable traits
- **genital herpes** an STI caused by the herpes simplex virus
- **genital warts** soft, pink, irregular growths that develop in the external genitalia or anus as a result of human papillomavirus infection
- **genome** entire genetic content of a cell
- **genomic library** a repository of an organism's entire genome maintained as cloned fragments in the genomes of strains of a host organism
- **genomics** the study and comparison of entire genomes, including the complete set of genes, their nucleotide sequence and organization, and their interactions within a species and with other species
- **genotype** full collection of genes that a cell contains within its genome
- **germ theory of disease** the theory that many diseases are the result of microbial infection
- **germination** process of an endospore returning to the vegetative state
- **Ghon complex** calcified lesion containing *Mycobacterium tuberculosis*; forms in the lungs of patients with tuberculosis
- **giardiasis** intestinal infection caused by *Giardia lamblia*
- **gingivitis** inflammation of the gums that can cause bleeding
- **glial cell** assists in the organization of neurons, provides a scaffold for some aspects of neuron function, and aids in recovery from neural injury
- **glomerulonephritis** a type of kidney infection involving the glomeruli of the nephrons
- **glomerulus** capillary bed in the nephron of the kidney that filters blood to form urine
- **glycocalyx** cell envelope structure (either capsules or slime layer) outside the cell wall in some bacteria; allows bacteria to adhere to surfaces, aids in biofilm formation, and provides protection from predation
- **glycogen** highly branched storage polysaccharide in animal cells and bacteria
- **glycolipid** complex lipid that contains a carbohydrate moiety
- **glycolysis** first step in the breakdown of glucose, the most common example of which is the Embden-Meyerhoff-Parnas pathway,

producing two pyruvates, two NADH molecules, and two (net yield) ATP per starting glucose molecule

- **glycopeptides** class of antibacterials that inhibit cell wall synthesis by binding to peptidoglycan subunits and blocking their insertion into the cell wall backbone, as well as blocking transpeptidation
- **glycoprotein** conjugated protein with a carbohydrate attached
- **glycosidic bond** forms between the hydroxyl groups of two sugar molecules
- **Golgi apparatus** an organelle of the endomembrane system that is composed of a series of flattened membranous disks, called dictyosomes, each having a single lipid bilayer, that are stacked together; important in the processing of lipids and proteins
- **gonorrhea** a common STI of the reproductive system caused by *Neisseria gonorrhoeae*
- **graft-versus-host disease** specific type of transplantation reaction in which a transplanted immune system (e.g., a bone marrow transplant) contains APCs and T cells that are activated and attack the recipient's tissue
- **Gram stain procedure** a differential staining technique that distinguishes bacteria based upon their cell wall structure
- **granulocytes** leukocytes found in the peripheral blood that are characterized by numerous granules in the cytoplasm; granulocytes include neutrophils, eosinophils, and basophils
- **granuloma** walled-off area of chronically inflamed tissue containing microbial pathogens, macrophages, and cellular materials unable to be eliminated
- **granulomatous amoebic encephalitis (GAE)** serious brain infection of immunocompromised individuals caused by *Acanthamoeba* or *Balamuthia mandrillaris*
- **granzymes** proteases released from a natural killer cell that enter the cytoplasm of a target cell, inducing apoptosis
- **Graves disease** hyperthyroidism caused by an autoimmune disease affecting thyroid function
- **green nonsulfur bacteria** similar to green sulfur bacteria but use substrates other than sulfides for oxidation
- **green sulfur bacteria** phototrophic, anaerobic bacteria that use sulfide for oxidation and produce large amounts of green bacteriochlorophyll

- **growth curve** a graph modeling the number of cells in a culture over time
- **guanine** purine nitrogenous base found in nucleotides
- **Guillain-Barré syndrome** an autoimmune disease, often triggered by bacterial and viral infections, characterized by the destruction of myelin sheaths around neurons, resulting in flaccid paralysis
- **gummas** granulomatous lesions that develop in tertiary syphilis

H

- **hair follicle** a structure embedded in the dermis from which hair grows
- **halophile** organism that depends on high concentrations of salt in the environment to grow
- **halotolerant** organism that grows in the presence of high salt concentration but does not require it
- **Hansen's Disease** chronic bacterial infection of peripheral nervous tissues caused by the acid-fast bacterium, *Mycobacterium leprae*; also known as leprosy
- **hantavirus pulmonary syndrome** acute lung infection by a hantavirus following inhalation of aerosols from the urine or feces of infected rodents
- **haploid** having one copy of each chromosome
- **haptin** a molecule that is too small to be antigenic alone but becomes antigenic when conjugated to a larger protein molecule
- **hard chancre** a generally painless ulcer that develops at the site of infection in primary syphilis
- **Hashimoto thyroiditis** hypothyroidism caused by an autoimmune disease affecting thyroid function
- **healthcare-associated infection (HAI)** an infection acquired in a hospital or other health-care facility unrelated to the reason for which the patient was initially admitted; nosocomial infection
- **heavy chains** longest identical peptide chains in antibody molecules (two per antibody monomer), composed of variable and constant region segments
- **helical virus** cylindrical or rod shaped

- **helicase** enzyme that unwinds DNA by breaking the hydrogen bonds between the nitrogenous base pairs, using ATP
- **helminth** a multicellular parasitic worm
- **helper T cells** class of T cells that is the central orchestrator of the cellular and humoral defenses of adaptive immunity and the cellular defenses of innate immunity
- **hemagglutination** visible clumping of red blood cells that can be caused by some viruses, bacteria, and certain diseases in which antibodies are produced that bind to self-red blood cells
- **hematopoiesis** formation, development, and differentiation of blood cells from pluripotent hematopoietic stem cells
- **hematuria** condition in which there is blood in the urine
- **hemolysin** class of exotoxin that targets and lyses red blood cells, as well as other cells
- **hemolytic disease of the newborn (HDN)** type II hypersensitivity reaction that occurs when maternal anti-Rh antibodies cross the placenta and target fetal Rh⁺ red blood cells for lysis
- **hemolytic transfusion reaction (HTR)** condition resulting after an incompatible blood transfusion; caused by type II hypersensitivity reaction and destruction of red blood cells
- **hemorrhagic fever with renal syndrome** serious hemorrhagic fever caused by hantavirus infection
- **HEPA filter** high-efficiency particulate air filter with an effective pore size that captures bacterial cells, endospores, and viruses as air passes through, removing them from the air
- **hepatitis** inflammation of the liver
- **herd immunity** a reduction in disease prevalence brought about when few individuals in a population are susceptible to an infectious agent
- **herpes keratitis** eye infection caused by herpes simplex virus
- **herpes simplex virus type 2 (HSV-2)** the type of herpesvirus most commonly associated with genital herpes
- **herpetic gingivostomatitis** inflammation of the mouth and gums often caused by the HSV-1 virus
- **heterolactic fermentation** process producing a mixture of lactic acid, ethanol and/or acetic acid, and CO₂ as fermentation products; the microbes that do this use pentose phosphate pathway glycolysis, which is why they generate multiple fermentation products

- **heterotroph** organism that uses fixed organic carbon compounds as its carbon source
- **hexose monophosphate shunt** see *pentose phosphate pathway*
- **Hfr cell** *E. coli* cell in which an F plasmid has integrated into the host cell's chromosome
- **high G+C gram-positive bacteria** bacteria that have more than 50% guanine and cytosine nucleotides in their DNA
- **high-energy phosphate bond** bond between the negatively charged phosphate groups that holds a lot of potential energy
- **histamine** proinflammatory molecule released by basophils and mast cells in response to stimulation by other cytokines and chemical mediators
- **histones** DNA-binding proteins found in eukaryotes and archaea that aid in orderly packaging of chromosomal DNA
- **histoplasmosis** fungal disease caused by the dimorphic fungus *Histoplasma capsulatum*
- **holoenzyme** enzyme with a bound cofactor or coenzyme
- **holozoic** refers to protozoans that consume food particles through phagocytosis
- **homolactic fermentation** process producing only lactic acid as a fermentation product; the microbes that do this use Embden-Meyerhof-Parnas glycolysis
- **hookworm infection** soil-transmitted intestinal infection caused by the nematodes *Necator americanus* and *Ancylostoma doudenale*
- **horizontal direct transmission** movement of a pathogen from one host to another (excluding mother to embryo, fetus, or infant) in a population through physical contact or through droplet transmission
- **horizontal gene transfer** introduction of genetic material from one organism to another organism within the same generation
- **host range** the types of host cells that a particular virus is able to infect
- **HTST** high-temperature short-time pasteurization is a method of pasteurization commonly used for milk in which the milk is exposed to a temperature of 72 °C for 15 seconds
- **human African trypanosomiasis** serious infection caused by *Trypanosoma brucei* and spread by the bite of the tsetse fly

- **human granulocytic anaplasmosis** zoonotic tickborne disease caused by the obligate intracellular pathogen *Anaplasma phagocytophilum*
- **human immunodeficiency virus (HIV)** retrovirus responsible for acquired immune deficiency syndrome (AIDS) in humans
- **human papillomavirus (HPV)** a group of common sexually transmitted viruses that may be associated with genital warts or with cervical cancer
- **humanized monoclonal antibodies** chimeric antibodies with mouse variable regions and human constant regions
- **humoral immunity** adaptive immunity mediated by antibodies produced by B cells
- **hyaluronidase** enzyme produced by pathogens that degrades hyaluronic acid between adjacent cells in connective tissue
- **hybridization** the joining of two complementary single-stranded DNA molecules
- **hybridoma** clones of cell produced by fusing a normal B cell with a myeloma cell that is capable of producing monoclonal antibodies indefinitely
- **hydatid disease** cystic echinococcosis, an infection caused by the tapeworm *Echinococcus granulosus*
- **hydrophilic** “water loving”; refers to a polar molecule or portion of a molecule capable of strong attraction to water molecules
- **hydrophobic** “water fearing”; refers to a nonpolar molecule or portion of a molecule not capable of strong attraction to water molecules
- **hypersensitivity pneumonitis (HP)** type III and IV hypersensitivities in the lungs that are caused by environmental or occupational exposure to allergens such as mold and dust
- **hypersensitivity** potentially damaging immune response against an antigen
- **hyperthermophile** a microorganism that has an optimum growth temperature close to the temperature of boiling water
- **hypertonic medium** an environment in which the solute concentration outside a cell exceeds that inside the cell, causing water molecules to move out of the cell, resulting in crenation (shriveling) or plasmolysis.
- **hyphae** tubular, filamentous structures that makes up most fungi
- **hypodermis** the layer of tissue under the dermis, consisting primarily of fibrous and adipose connective tissue

- **hypotonic medium** an environment in which the solute concentration inside a cell exceeds that outside the cell, causing water molecules to move into the cell, possibly leading to swelling and possibly lysis

I

- **iatrogenic disease** disease caused by or acquired during a medical procedure
- **icosahedral** three-dimensional, 20-sided structure with 12 vertices
- **IgA** antibody dimer primarily found in breast milk, mucus, saliva, and tears
- **IgD** membrane-bound antibody monomer functioning as receptor on the surface of B cells
- **IgE** antibody monomer involved in defense against parasites and allergic reactions
- **IgG** antibody monomer most abundant in serum; able to cross placenta; most versatile class of antibody in terms of function
- **IgM** antibody that is a monomer when functioning as a receptor on surface of B cells but a pentamer when secreted in response to specific pathogens; first antibody to respond during primary and secondary responses
- **illuminator** the light source on a microscope
- **image point (focus)** a property of the lens and the distance of the object to the lens; the point at which an image is in focus (the image point is often called the focus)
- **imidazoles** class of antifungal drugs that inhibit ergosterol biosynthesis
- **immune complex** large group of antigens bound by antibodies; large enough to settle out of fluid suspension
- **immunochromatographic assay** assay in which fluids are pulled through test strips by capillary action and antigen captured by mobile antibody-colored bead conjugates; a second, fixed antibody localizes the colored bead, allowing visualization
- **immunocytochemistry (ICC)** staining technique in which cells are fixed and holes dissolved in the membrane to allow passage of labeled antibodies to bind specific intracellular targets

- **immuno-electrophoresis (IEP)** assay following protein electrophoresis (PAGE) of serum, in which antisera against specific serum proteins are added to troughs cut parallel to the electrophoresis track, causing the formation of precipitin arcs
- **immunofiltration** technique in which antibody or antigen can be concentrated by passing fluids through porous membranes, and target molecules are captured as they pass
- **immunofluorescence** a technique that uses a fluorescence microscope and antibody-specific fluorochromes to determine the presence of specific pathogens in a specimen
- **immunoglobulin** antibody
- **immunohistochemistry (IHC)** staining technique in which labeled antibodies are bound to specific cells in a tissue section
- **immunology** the study of the immune system
- **immunostain** use of EIA technology to deliver stain to particular cells in a tissue (immunohistochemistry) or specific targets within a cell (immunocytochemistry)
- **impetigo** a skin infection that may result in vesicles, blisters, or bullae especially around the mouth, commonly caused by *Staphylococcus aureus*, *S. pyogenes*, or a combination of both *S. aureus* and *S. pyogenes*
- **in vitro** outside the organism in a test tube or artificial environment
- **in vivo** inside the organism
- **inactivated vaccine** vaccine composed of whole pathogen cells or viruses that have been killed or inactivated through treatment with heat, radiation, or chemicals
- **incidence** the number of individuals with new infections of a particular disease in a given period of time
- **inclusion conjunctivitis** inflammation of the conjunctiva in newborns caused by *Chlamydia trachomatis* transmitted during childbirth
- **inclusions** prokaryotic cell cytoplasmic structures for storing specific nutrients and other resources needed by cells
- **incubation period** the first stage of acute disease, during which the pathogen begins multiplying in the host and signs and symptoms are not observable
- **indirect agglutination assay** assay that can be used to detect the agglutination of small latex beads; beads may be coated with antigen

when looking for the presence of specific antibodies, or with antibody when looking for the presence of antigen

- **indirect antiglobulin test (IAT)** see indirect Coombs' test
- **indirect contact transmission** transfer of an infectious agent between hosts through contact with a fomite
- **indirect Coombs' test** assay, performed *in vitro* prior to blood transfusions, that looks for antibodies against red blood cell antigens (other than the A and B antigens) that are unbound in a patient's serum
- **indirect ELISA** EIA in which an antigen from a pathogen is first attached to the wells of a microtiter plate; the antigen then captures antibodies from patient serum to determine whether the patient currently has or previously had the disease
- **indirect fluorescent antibody test** assay for antigen-specific antibodies wherein the antigen captures the antibody, which is subsequently detected using a labeled anti-immunoglobulin mAb
- **induced mutation** mutation caused by a mutagen
- **inducer** small molecule that either activates or represses transcription
- **inducible operon** bacterial operon, typically containing genes encoding enzymes in a degradative pathway, whose expression is induced by the substrate to be degraded when the substrate is available for the cell to use, but that is otherwise repressed in the absence of the substrate
- **induction** prophage DNA is excised from the bacterial genome
- **infection** the successful colonization of a microorganism within a host
- **infectious arthritis (septic arthritis)** inflammation of joint tissues in response to a microbial infection
- **infectious disease** disease caused by a pathogen
- **infectious mononucleosis** common and mild infection caused by Epstein-Barr virus (HHV-4) or cytomegalovirus (HHV-5); transmitted by direct contact with body fluids such as saliva
- **inflammation** innate nonspecific immune response characterized by erythema, edema, heat, pain, and altered function, typically at the site of injury or infection but sometimes becoming systemic.
- **influenza** highly contagious and acute viral disease of the respiratory tract caused by the influenza virus
- **initiation factors** proteins that participate in ribosome assembly during initiation

- **initiation of DNA replication** stage of replication during which various proteins bind to the origin of replication to begin the replication process
- **initiation of transcription** stage of transcription during which RNA polymerase binds to a promoter and transcription begins
- **initiation of translation** stage of translation during which an initiation complex composed of the small ribosomal subunit, the mRNA template, initiation factors, GTP, and a special initiator tRNA forms, and the large ribosomal subunit then binds to the initiation complex
- **inoculum** small number of cells added to medium to start a culture
- **inorganic phosphate (P_i)** single phosphate group in solution
- **insertion** type of mutation involving the addition of one or more bases into a DNA sequence
- **integrase inhibitors** antiviral drugs that block the activity of the HIV integrase responsible for recombination of a DNA copy of the viral genome into the host cell chromosome
- **intercalating agent** molecule that slides between the stacked nitrogenous bases of the DNA double helix, potentially resulting in a frameshift mutation
- **interference** distortion of a light wave due to interaction with another wave
- **interferons** cytokines released by cells that have been infected with a virus; stimulate antiviral responses in nearby cells as well as the cells secreting the interferons
- **interleukins** cytokines largely produced by immune system cells that help coordinate efforts against invading pathogens
- **intermediate filament** one of a diverse group of cytoskeletal fibers that act as cables within the cell and anchor the nucleus, comprise the nuclear lamina, or contribute to the formation of desmosomes
- **intermediate host** a host in which a parasite goes through some stages of its life cycle before migrating to the definitive host
- **intermittent common source spread** a mode of disease transmission in which every infection originates from the same source and that source produces infections for a period before stopping and then starting again
- **intertrigo** a rash that occurs in a skin fold

- **intestinal fluke** a trematode worm that infects the intestine, often caused by *Fasciolopsis buski*
- **intracellular targeting toxin** *see A-B exotoxin*
- **intrinsic growth rate** genetically determined generation time under specific conditions for a bacterial strain
- **intron** intervening sequence of a eukaryotic gene that does not code for protein and whose corresponding RNA sequences are removed from the primary transcript during splicing
- **intubation** placement of a tube into the trachea, generally to open the airway or to administer drugs or oxygen
- **in-use test** a technique for monitoring the correct use of disinfectants in a clinical setting; involves placing used, diluted disinfectant onto an agar plate to see if microbial colonies will grow
- **invasion** dissemination of a pathogen through local tissues or throughout the body
- **iodophor** compound in which iodine is complexed to an organic molecule, increasing the stability and efficacy of iodine as a disinfectant
- **ionizing radiation** high-energy form of radiation that is able to penetrate surfaces and sterilize materials by damaging microbial cell components and DNA
- **ischemia** condition marked by the inadequate flow of blood to the tissues
- **isograft** tissue grafted from one monozygotic twin to another
- **isohemagglutinins** IgM class antibodies produced against A or B red blood cell antigens
- **isomers** molecules that have the same atomic makeup but differ in the structural arrangement of the atoms
- **isoniazid** antimetabolite that inhibits biosynthesis of mycolic acid; used for the treatment of mycobacterial infections
- **isoprenoid** branched lipid derived from five-carbon isoprene molecules
- **isotonic medium** a solution in which the solute concentrations inside and outside the cell are approximately equal, thereby creating no net movement of water molecules across the cell membrane
- **ivermectin** antihelminthic drug of the avermectin class that binds to invertebrate glutamate-gated chloride channels to block neuronal

transmission in helminths

J

- **Japanese encephalitis** arboviral disease caused by the Japanese encephalitis virus (JEV) and endemic to Asia
- **jaundice** yellowish color of the skin and mucous membranes caused by excessive bilirubin caused by a failure of the liver to effectively process the breakdown of hemoglobin

K

- **keratin** a fibrous protein found in hair, nails, and skin
- **keratitis** inflammation of the cornea
- **keratoconjunctivitis** inflammation of both the cornea and the conjunctiva
- **kidney** organ that filters the blood, producing urine
- **Kinyoun technique** a method of acid-fast staining that does not use heat to infuse the primary stain, carbolfuchsin, into acid-fast cells
- **Kirby-Bauer disk diffusion test** simple, rapid method for determining susceptibility and resistance of a bacterial pathogen to antibacterial drugs. The test involves drug-impregnated disks placed on an agar plate inoculated with a bacterial lawn.
- **Koplik's spots** white spots that form on the inner lining of the cheek of patients with measles
- **Krebs cycle** cyclic pathway during which each two-carbon unit entering the cycle is further oxidized, producing three NADH, one FADH₂, and one ATP by substrate-level phosphorylation, releasing two CO₂ molecules and regenerating the molecule used in the first step; also called the *citric acid cycle* or the *tricarboxylic acid cycle*
- **kuru** rare form of transmissible spongiform encephalopathy endemic to Papua New Guinea

L

- **lacrimal duct** connects the lacrimal gland to the lacrimal sac
- **lacrimal gland** a gland situated above the eye that secretes tears
- **lacrimal punctum** opening in each upper and lower eyelid
- **lacrimal sac** a to a reservoir for tears; also known as the dacrocyst or tear sac
- **lag period** the time between antigen exposure and production of antibodies
- **lag phase** interval before exponential growth of a microbial population during which cells adjust to a new environment
- **lagging strand** strand of DNA made discontinuously by DNA polymerase
- **laryngitis** inflammation of the larynx
- **laryngopharynx** lower portion of the pharynx that connects to the larynx
- **larynx** region of the respiratory tract containing the vocal cords; also referred to as the voice box
- **latent disease** disease that goes into a dormant nonreplicative state after the acute disease and can persist in this state for years, with the risk of reactivation back into acute disease
- **latent virus** virus that remains dormant in the host genome
- **lateral flow test** see immunochromatographic assays
- **leading strand** strand of DNA made continuously in the 5' to 3' direction by DNA polymerase
- **Legionnaires disease** atypical pneumonia occurring in older individuals; caused by the inhalation of *Legionella pneumophila* aerosolized in water
- **leishmaniasis** protozoan infection caused by *Leishmania* spp. and transmitted by sand flies
- **leprosy** see *Hansen's disease*
- **leptospirosis** bacterial infection of the kidney caused by *Leptospira* spp.; may spread to the liver, lungs, brain, and other organs
- **leukocidin** class of exotoxin that targets and lyses leukocytes
- **leukocytes** white blood cells of various types, including granulocytes, lymphocytes, and monocytes

- **leukotrienes** lipid-based chemical mediators produced by leukocytes and other tissue cells; promote inflammation and allergic responses
- **lichen** symbiotic association of a fungus with an algae or cyanobacterium
- **ligation** repair of the sugar-phosphate backbone of the DNA, making the DNA molecule continuous
- **light chains** the shorter identical peptide chains of an antibody molecule (two per antibody monomer), composed of variable and constant region segments
- **light-dependent reaction** process by which energy from sunlight is absorbed by pigment molecules in photosynthetic membranes and converted into stored chemical energy in the forms of ATP and NADPH
- **light-harvesting complex** group of multiple proteins and associated pigments that each may absorb light energy to become excited, and transfer this energy from one pigment molecule to another until the energy is delivered to a reaction center pigment
- **light-independent reaction** process by which chemical energy, in the form of ATP and NADPH produced by the light-dependent reactions, is used to fix inorganic CO₂ into organic sugar; usually referred to as the Calvin-Benson cycle
- **lincomycin** naturally produced protein synthesis inhibitor of the lincosamide class that binds to the 50S subunit, inhibiting peptide bond formation
- **lincosamides** class of protein synthesis inhibitors that are similar to macrolides
- **linked recognition** a mechanism whereby a B cell and the helper T cell with which it interacts recognize the same antigen
- **lipase** extracellular enzyme that degrades triglycerides
- **lipid bilayer** biological membranes composed of two layers of phospholipid molecules with the nonpolar tails associating to form a hydrophobic barrier between the polar heads; also called unit membrane
- **lipid** macromolecule composed primarily of carbon and hydrogen; source of nutrients for organisms, a storage form for carbon and energy, a part of the structure of membranes, and may function as hormones, pharmaceuticals, fragrances, and pigments

- **lipopolysaccharide (LPS)** lipid molecules with attached sugars that are found as components of gram-negative outer membranes
- **lipoprotein** conjugated protein attached to a lipid
- **listeriosis** bacterial disease caused from the ingestion of the microbe *Listeria monocytogenes*
- **lithotroph** chemotroph that uses inorganic chemicals as its electron source; also known as chemoautotroph
- **live attenuated vaccine** vaccine with live pathogen that has been attenuated to become less virulent in order to produce an active but subclinical infection
- **liver fluke** a trematode worm that affects the bile duct of the liver, including *Fasciola hepatica* and *F. gigantica*
- **local infection** infection in one limited area
- **log phase** interval of growth when cells divide exponentially; also known as the exponential growth phase
- **loiasis** a disease caused by the parasitic *Loa loa* worm, which is transmitted by deerflies; adult worms live in the subcutaneous tissue and cause inflammation, swelling, and eye pain as they migrate through the skin and the conjunctiva of the eye
- **lophotrichous** having a single tuft of flagella located at one end of a bacterial cell
- **low G+C gram-positive bacteria** bacteria that have less than 50% of guanine and cytosine nucleotides in their DNA
- **lumen** space inside the cisternae of the endoplasmic reticulum in eukaryotic cells
- **Lyme disease** tickborne disease caused by the spirochete *Borrelia burgdorferi*
- **lymph nodes** bean-shaped organs situated throughout the body that contain areas called germinal centers, which are rich in B and T lymphocytes; also contain macrophages and dendritic cells for antigen presentation
- **lymphadenitis** inflammation of the lymph nodes
- **lymphangitis** inflammation of the lymphatic vessels
- **lymphogranuloma venereum** infection caused by *Chlamydia trachomatis* in tropical regions
- **lyophilization** rapid freezing, followed by placement under a vacuum, of a material so that water is lost by sublimation, thereby inhibiting

microbial growth

- **lysis** destruction of the host cell
- **lysogen** bacterium carrying the prophage
- **lysogenic conversion (phage conversion)** alteration of host characteristics or phenotypes due to the presence of phage
- **lysogenic cycle** life cycle of some phages in which the genome of the infecting phage is integrated into the bacterial chromosome and replicated during bacterial reproduction until it excises and enters a lytic phase of the life cycle
- **lysogeny** process of integrating the phage into the host genome
- **lysosome** an organelle of the endomembrane system that contains digestive enzymes that break down engulfed material such as foodstuffs, infectious particles, or damaged cellular components
- **lytic cycle** infection process that leads to the lysis of host cells

M

- **M protein** a streptococcal cell wall protein that protects the bacteria from being phagocytized. It is associated with virulence and stimulates a strong immune response
- **macrolides** class of protein synthesis inhibitors containing a large, complex ring structure that binds to the 50S subunit, inhibiting peptide bond formation
- **macromolecule** polymer assembled from individual units, monomers, that bind together like building blocks
- **macronucleus** larger nucleus in ciliate protists that have two nuclei; polyploid with a reduced genome of metabolic genes and derived from the micronucleus
- **macronutrient** element required in abundance in cells; account for approximately 99% of the cell's dry weight
- **macrophages** monocytes that have left the bloodstream and differentiated into tissue-specific phagocytes
- **mad cow disease** form of transmissible spongiform encephalopathy primarily affecting cattle; can be transmitted to humans by consumption of contaminated cattle products

- **magnetosomes** inclusions in certain bacterial cells containing magnetic iron oxide or iron sulfide, which allows bacteria to align along a magnetic field by magnetotaxis
- **magnetotaxis** directional movement of bacterial cells using flagella in response to a magnetic field
- **magnification** the power of a microscope (or lens) to produce an image that appears larger than the actual specimen, expressed as a factor of the actual size
- **major histocompatibility complex (MHC)** collection of genes that code for MHC glycoproteins expressed on the surface of all nucleated cells
- **malaise** a general feeling of being unwell
- **malaria** potentially fatal, mosquito-borne protozoan infection caused by several species of *Plasmodium* and characterized by a relapsing fever, nausea, vomiting, and fatigue
- **mast cells** granulocytes similar in origin and function to basophils, but residing in tissues
- **matrix assisted laser desorption/ionization time of flight mass spectrometry (MALDI-TOF)** technique in which the sample (e.g., a microbe colony) is mixed with a special matrix and irradiated with a high-energy laser to generate characteristic gaseous ions that are subjected to mass spectral analysis, yielding mass spectra that may be compared to reference data for identification purposes
- **maturation** assembly of viral components to produce a functional virus
- **mature naïve T cell** a T cell that has exited the thymus after thymic selection but has not yet been activated
- **maximum growth pH** highest pH value that an organism can tolerate for growth
- **maximum growth temperature** highest temperature at which a microorganism will divide or survive
- **maximum permissible oxygen concentration** highest concentration of oxygen at which an organism will grow
- **measles** highly contagious respiratory disease caused by the measles virus (MeV); marked by an intense macular rash and high fever; also known as rubeola

- **mebendazole** antihelminthic drug of the benzimidazole class that binds to helminthic β -tubulin, preventing microtubule formation
- **mechanical transmission** transfer of a pathogen between hosts by a mechanical vector
- **mechanical vector** an animal that transfers a pathogen from one host to another or from a reservoir to a host without being infected by the pathogen itself
- **median infectious dose (ID_{50})** concentration of pathogen that will produce active infection in 50% of test animals inoculated
- **median lethal dose (LD_{50})** concentration of pathogen that kills 50% of infected test animals
- **medulla** loosely packed layer of fungal filaments located underneath the cortex of a lichen
- **membrane attack complex (MAC)** ring structure formed from complement proteins C6 through C9 that penetrates the membranes of a targeted cell, causing cell lysis and death
- **membrane filtration** method to remove bacteria from liquid, typically heat-sensitive solutions, using filters with an effective pore size of 0.2 μm or smaller, depending on need
- **membrane filtration technique** known volumes are vacuum filtered aseptically through a membrane with a pore size small enough to trap microorganisms, which are counted after growth on plates
- **membrane-bound ribosome** 80S eukaryotic ribosome attached to rough endoplasmic reticulum
- **membrane-disrupting toxin** toxin that affects cell membrane function by either forming pores or disrupting the phospholipid bilayer
- **memory B cell** an activated and differentiated B cell that is programmed to respond to secondary exposures to a specific antigen
- **memory helper T cell** a long-lived T cell programmed to recognize and quickly mount a secondary response to a specific pathogen upon re-exposure
- **memory** the ability of the specific adaptive immune system to quickly respond to pathogens to which it has previously been exposed
- **meninges** membranes that surround the brain
- **meningitis** inflammation of the meningeal membranes that surround the brain

- **meningococcal meningitis** bacterial infection caused by *Neisseria meningitidis* that results in an inflammation of the meninges
- **meningoencephalitis** inflammatory response that involves both the brain and the membranes that surround it
- **MERS** Middle East respiratory syndrome; first described in Saudi Arabia in 2013; caused by a zoonotic coronavirus that results in flu-like symptoms
- **mesophile** a microorganism that grows best at moderate temperatures, typically between about 20 °C and 45 °C
- **metabolism** all of the chemical reactions inside of cells
- **metachromatic granule** a type of inclusion containing volutin, a polymerized inorganic phosphate that appears red when stained with methylene blue
- **metagenomics** the sequencing of genomic fragments from microbial communities, allowing researchers to study genes from a collection of multiple species
- **metatranscriptomics** the science of studying a collection of mRNA molecules produced from microbial communities; involves studying gene expression patterns from a collection of multiple species
- **methanogen** microorganism that produces gaseous methane
- **methicillin-resistant *Staphylococcus aureus* (MRSA)** pathogen resistant to all β -lactams through acquisition of a new low-affinity penicillin-binding protein, and often resistant to many other drug classes
- **metronidazole** antibacterial and antiprotozoan drug of the nitroimidazole class that is activated in anaerobic target cell and introduces DNA strand breakage, thus interfering with DNA replication in target cells
- **MHC I molecule** glycoprotein expressed on the surface of all nucleated cells and involved in the presentation of normal “self” antigens and foreign antigens from intracellular pathogens
- **MHC II molecule** glycoprotein expressed only on the surface of antigen-presenting cells and involved in the presentation of foreign antigens from pathogens ingested by phagocytosis
- **micelle** simple spherical arrangement of amphipathic lipid molecules with nonpolar tails aggregated within the interior and polar heads forming the outer surface

- **microaerophile** organism that requires oxygen at levels lower than atmospheric concentration
- **microarray analysis** a technique used to compare two samples of genomic DNA or cDNA; the DNA or cDNA fragments are immobilized on a chip and labeled with different fluorescent dyes, allowing for comparison of sequences or gene-expression patterns
- **microbe** generally, an organism that is too small to be seen without a microscope; also known as a microorganism
- **microbial death curve** graphical representation of the progress of a particular microbial control protocol
- **microbial ecology** study of the interactions between microbial populations microbiology the study of microorganisms
- **microbiome** all prokaryotic and eukaryotic microorganisms that are associated with a certain organism
- **microfilament** cytoskeletal fiber composed of actin filaments
- **microinjection** the direct injection of DNA into the cytoplasm of a eukaryotic cell using a glass micropipette
- **micronucleus** smaller nucleus in ciliate protists that have two nuclei; diploid, somatic, and used for sexual reproduction through conjugation
- **micronutrient** indispensable element present in cells in lower amounts than macronutrients; also called *trace element*
- **microorganism** generally, an organism that is too small to be seen without a microscope; also known as a microbe
- **microsporidia** fungi that lack mitochondria, centrioles, and peroxisomes; some can be human pathogens
- **microtiter plates** plastic dishes with multiple small wells
- **microtubule** hollow tube composed of tubulin dimers (α and β tubulin); the structural component of the cytoskeleton, centrioles, flagella, and cilia
- **miliary tuberculosis** hematogenous dissemination and spread of *Mycobacterium tuberculosis* from tubercles
- **minimal bactericidal concentration (MBC)** lowest antibacterial drug concentration that kills $\geq 99.9\%$ of a starting inoculum of bacteria
- **minimal inhibitory concentration (MIC)** lowest concentration of an antibacterial drug that inhibits visible growth of a bacterial strain
- **minimum growth pH** lowest pH value that an organism can tolerate for growth

- **minimum growth temperature** lowest temperature at which a microorganism will divide or survive
- **minimum permissible oxygen concentration** lowest concentration of oxygen at which an organism will grow
- **missense mutation** point mutation that results in a different amino acid being incorporated into the resulting polypeptide
- **mitochondrial matrix** the innermost space of the mitochondrion enclosed by two membranes; the location of many metabolic enzymes as well as the mitochondrial DNA and 70S ribosomes
- **mitochondrion (plural: mitochondria)** large, complex organelle that is the site of cellular respiration in eukaryotic cells
- **mode of action** way in which a drug affects a microbe at the cellular level
- **moist-heat sterilization** protocol that involves steam under pressure in an autoclave, allowing the steam to reach temperatures higher than the boiling point of water
- **mold** a multicellular fungus, typically made up of long filaments
- **molecular cloning** the purposeful fragmentation of DNA followed by attachment to another piece of DNA to produce a recombinant molecule, followed by introduction of this recombinant molecule into an easily manipulated host to allow for the creation of multiple copies of a gene of interest
- **monoclonal antibodies (mAbs)** antibodies produced *in vitro* that only bind to a single epitope
- **monocular** having a single eyepiece
- **monocytes** large, agranular, mononuclear leukocytes found in the peripheral blood; responsible for phagocytosis of pathogens and damaged cells
- **monoecious** refers to sexually reproducing organisms in which individuals have both male and female reproductive organs
- **monomer** small organic molecule that binds with like molecules, forming a polymer or macromolecule
- **monosaccharide** monomer for the synthesis of carbohydrate polymers; the simplest carbohydrate, called a *simple sugar*
- **monotrichous** having one flagellum, typically located on one end of the bacterial cell
- **morbidity** a state of illness

- **Morbidity and Mortality Weekly Report (MMWR)** the trade/industry publication for epidemiologists, reporting US public health data compiled by the CDC
- **morbidity rate** the number of cases of a disease expressed as a percentage of the population or number per standard part of the population, such as 100,000
- **mordant** a chemical added to a specimen that sets a stain
- **mortality** death
- **mortality rate** the number of deaths from a disease expressed as a percentage of the population or number per standard part of the population, such as 100,000
- **most probable number (MPN)** statistical value representing the viable bacterial population in a sample obtained after a series of dilutions and multiple tube inoculations
- **mRNA** short-lived type of RNA that serves as the intermediary between DNA and the synthesis of protein products
- **mucociliary escalator** system by which mucus and debris are propelled up and out of the respiratory tract by the beating of respiratory cilia and the mechanical actions of coughing or swallowing
- **mucormycosis** rare form of pneumonia that can be caused by an invasive infection of different fungi in the order Mucorales, such as *Rhizopus* or *Mucor*
- **mucous membrane** moist layer of epithelial cells and interspersed goblet cells that lines the inner surfaces of the body, usually bathed in antimicrobial secretions from the cells of the membrane
- **mucus** viscous secretion produced by cells and glands in various mucous membranes throughout the body; helps trap and remove microbes and debris from the body
- **multidrug-resistant microbes (MDR)** group of pathogens that carry one or more resistance mechanisms, making them resistant to multiple antimicrobials; also called superbugs
- **multidrug-resistant *Mycobacterium tuberculosis* (MDR-TB)** strains of *M. tuberculosis* that are resistant to both rifampin and isoniazid, the drug combination typically prescribed for the treatment of tuberculosis
- **multiple sclerosis** autoimmune attack on the myelin sheaths and nerve cells in the central nervous system

- **mumps** a viral illness that causes swelling of the parotid glands; rare in the United States because of effective vaccination
- **murine typhus** fleaborne infection caused by *Rickettsia typhi* and characterized by fever, rash, and pneumonia
- **mutagen** type of chemical agent or radiation that can induce mutations
- **mutant** organism harboring a mutation that often has a recognizable change in phenotype compared to the wild type
- **mutation** heritable change in the DNA sequence of an organism
- **mutualism** type of symbiosis in which two populations benefit from, and depend on, each other
- **myasthenia gravis** autoimmune disease affecting the acetylcholine receptors in the neuromuscular junction, resulting in weakened muscle contraction capability
- **mycelium** vegetative network of branched, tubular hyphae
- **mycolic acids** waxy molecules associated with peptidoglycan in some gram-positive, acid-fast bacteria, chiefly mycobacteria
- **mycology** the study of fungi
- **Mycoplasma pneumonia** also known as walking pneumonia; a milder form of atypical pneumonia caused by *Mycoplasma pneumoniae*
- **mycoses (mycosis, sing.)** refers to diseases caused by fungi
- **mycotoxin** biologically active product of pathogenic fungi that causes adverse changes in the host cells
- **myelin sheath** insulating layer that surrounds the axon of some neurons and helps to promote signal propagation
- **myocarditis** inflammation of the heart muscle tissues

N

- **naïve mature B cell** a B cell that has not yet been activated
- **naked virus** virus composed of a nucleic acid core, either DNA or RNA, surrounded by a capsid
- **nalidixic acid** member of the quinolone family that functions by inhibiting the activity of DNA gyrase, blocking DNA replication
- **narrow-spectrum antimicrobial** drug that targets only a specific subset of microbes
- **nasal cavity** air-filled space in the skull immediately behind the nose

- **nasolacrimal duct** tear duct connecting the lacrimal glands to the nasal cavity
- **nasolacrimal duct** tear fluid flows from each eye through this duct to the inner nose
- **nasopharynx** part of the upper throat (pharynx) extending from the posterior nasal cavity; carries air inhaled through the nose
- **native structure** three-dimensional structure of folded fully functional proteins
- **natural active immunity** immunity that develops as a result of natural infection with a pathogen
- **natural antibiotic** antimicrobial compound that is produced naturally by microorganisms in nature
- **natural killer cells (NK cells)** lymphoid cells that recognize and destroy abnormal target cells by inducing apoptosis
- **natural passive immunity** transfer of maternal antibodies from mother to fetus (transplacentally) or infant (via breastmilk)
- **necrotizing fasciitis** a serious infection, also known as flesh-eating disease, that leads to rapid destruction of tissue through the action of exotoxin A; it can be caused by *S. pyogenes* or several other bacterial species
- **negative (–) single-strand RNA (–ssRNA)** a viral RNA strand that cannot be translated until it is replicated into positive single-strand RNA by viral RNA-dependent RNA polymerase
- **negative stain** a stain that produces color around the structure of interest while not coloring the structure itself
- **Nematoda** phylum comprising roundworms
- **neonatal herpes** herpes infection of the newborn, generally caused by infection during birth
- **neonatal meningitis** meningitis caused by Group B streptococcus and occurring primarily in neonates (less than 2 months old)
- **neonatal tetanus** tetanus acquired through infection of the cut umbilical cord
- **neurocysticercosis** parasitic invasion of brain tissues by the larvae of the pork tapeworm, *Taenia solium*
- **neuromycosis** any fungal infection of the nervous system
- **neuron** specialized cell found throughout the nervous system that transmits signals through the nervous system using electrochemical

processes

- **neuropathy** numbness or tingling sensation caused by damage to peripheral nerves
- **neurotoxoplasmosis** disease caused by the invasion of brain tissues by the protozoan *Toxoplasma gondii*; typically only affects immunocompromised patients
- **neurotransmitter** compound that is released at the synapse of neurons to stimulate or suppress the actions of other cells
- **neutralism** type of symbiosis that does not affect either of the two populations
- **neutralization** binding of an antibody to a pathogen or toxin, preventing attachment to target cells
- **neutrophile** organism that grows best at a near a neutral pH of 6.5–7.5
- **neutrophils** leukocytes with a multilobed nucleus found in large numbers in peripheral blood; able to leave the bloodstream to phagocytose pathogens in infected tissues; also called polymorphonuclear neutrophils (PMNs)
- **next generation sequencing** a group of automated techniques used for rapid DNA sequencing
- **nicotine adenine dinucleotide (NAD⁺/NADH)** oxidized/reduced forms of an electron carrier in cells
- **nicotine adenine dinucleotide phosphate (NADP⁺/NADPH)** oxidized/reduced forms of an electron carrier in cells
- **nitrogen fixation** bacterial biochemical pathways that incorporate inorganic nitrogen gas into organic forms more easily used by other organisms
- **nitrogenous base** nitrogen-containing ring structure within a nucleotide that is responsible for complementary base pairing between nucleic acid strands
- **noncoding DNA** regions of an organism's genome that, unlike genes, do not encode proteins
- **noncommunicable disease** disease that is not transmitted from one person to another
- **noncompetitive (allosteric) inhibitor** molecule that binds to allosteric sites, inducing a conformational change in the enzyme's structure that prevents it from functioning

- **noncritical item** object that may contact intact skin but does not penetrate it; requires cleanliness but not a high level of disinfection
- **noncyclic photophosphorylation** pathway used in photosynthetic organisms when both ATP and NADPH are required by the cell
- **nonenveloped virus** naked virus
- **nongonococcal urethritis (NGU)** a nonspecific infection of the urethra that is not caused by *Neisseria gonorrhoeae*
- **noninfectious disease** disease caused by something other than an infectious agent (e.g., genetics, environment, nutritional deficiencies)
- **nonionizing radiation** low-energy radiation, like ultraviolet light, that can induce dimer formation between two adjacent pyrimidine bases, resulting in DNA polymerase stalling and possible formation of a frameshift mutation
- **nonsense mutation** point mutation that converts a codon encoding an amino acid (a sense codon) into a stop codon (a nonsense codon)
- **nontreponemal serologic tests** qualitative and quantitative indirect diagnostic tests for syphilis
- **northern blot** a technique in molecular genetics used to detect the amount of RNA made by gene expression within a tissue or organism sample; RNA fragments within a sample are separated by agarose gel electrophoresis, immobilized on a membrane, and then exposed to a specific DNA probe labeled with a radioactive or fluorescent molecular beacon to aid in detection
- **nosocomial disease** disease acquired in a hospital setting
- **notifiable disease** a disease for which all cases must legally be reported to regional, state, and/or federal public health agencies
- **nuclear envelope** (also called the nuclear membrane) a structure defining the boundary of the nucleus; composed of two distinct lipid bilayers that are contiguous with each other and with the endoplasmic reticulum
- **nuclear lamina** a meshwork of intermediate filaments (mainly lamins) found just inside the nuclear envelope; provides structural support to the nucleus
- **nucleic acid** class of macromolecules composed of nucleotide monomers polymerized into strands
- **nucleoid** concentrated area of DNA genome and associated proteins found in a prokaryotic cell that is not surrounded by a membrane

- **nucleoid-associated protein (NAP)** protein that assists in the organization and packaging of the chromosome in prokaryotic cells
- **nucleolus** a dense region within the nucleus where ribosomal RNA biosynthesis occurs and preribosomal complexes are made
- **nucleoside analog** chemical that is structurally similar to a normal nucleotide base that can be incorporated into DNA instead of normal bases during replication but that has different base pairing rules than the normal base for which it was substituted, inducing mutation
- **nucleotide excision repair (dark repair)** enzymatic mechanism to repair pyrimidine dimers by cutting the dimer-containing DNA strand on both sides of dimer, removing the intervening strand and replacing the bases with the correct ones
- **nucleotide** nucleic acid monomer composed of a pentose sugar, a phosphate group, and a nitrogenous base
- **nucleus** a membrane-bound structure of eukaryotic cells that houses the DNA genome
- **numerical aperture** a measure of a lens's ability to gather light

O

- **objective lenses** on a light microscope, the lenses closest to the specimen, typically located at the ends of turrets
- **obligate aerobe** organism that requires oxygen for growth
- **obligate anaerobe** organism that dies in the presence of oxygen
- **obligate intracellular pathogen** microorganism that cannot synthesize its own ATP and, therefore, must rely on a host cell for energy; behaves like a parasite when inside a host cell, but is metabolically inactive outside of a host cell
- **observational study** a type of scientific study that involves measurement of study subjects on variables hypothesized to be associated with the outcome of interest, but without any manipulation of the subjects
- **ocular lens** on a microscope, the lens closest to the eye (also called an eyepiece)
- **oil immersion lens** a special objective lens on a microscope designed to be used with immersion oil to improve resolution

- **Okazaki fragment** short fragment of DNA made during lagging strand synthesis
- **oligopeptide** peptide having up to approximately 20 amino acids
- **oligotroph** organism capable of living in low-nutrient environments
- **opacity** the property of absorbing or blocking light
- **operator** DNA sequence located between the promoter region and the first coding gene to which a repressor protein can bind
- **operon** a group of genes with related functions often found clustered together within the prokaryotic chromosome and transcribed under the control of a single promoter and operator repression sequence
- **ophthalmia neonatorum** inflammation of the conjunctiva in newborns caused by *Neisseria gonorrhoeae* transmitted during childbirth
- **opisthotonos** characteristic symptom of tetanus that results in uncontrolled muscular spasms and backward arching of the neck and spine
- **opportunistic pathogen** microorganism that can cause disease in individuals with compromised host defenses
- **opsonin** any molecule that binds to and coats the outside of a pathogen, identifying it for destruction by phagocytes (examples include antibodies and the complement proteins C3b and C4b)
- **opsonization** process of coating a pathogen with a chemical substance (an opsonin) that allows phagocytic cells to recognize, engulf, and destroy the pathogen more easily
- **optimum growth pH** the pH at which an organism grows best
- **optimum growth temperature** the temperature at which a microorganism's growth rate is highest
- **optimum oxygen concentration** the ideal concentration of oxygen for a particular microorganism
- **oral herpes** an infection caused by herpes simplex virus that results in cold sores, most commonly on and around the lips
- **oral thrush** *Candida* infection of the mouth
- **orchitis** inflammation of one or both of the testes
- **organic molecule** composed primarily of carbon; typically contains at least one carbon atom bound to one or more hydrogen atoms
- **organotroph** chemotroph that uses organic molecules as its electron source; also known as chemoheterotroph

- **origin of replication** specific nucleotide sequence where replication begins
- **oropharynx** area where air entering mouth enters the pharynx
- **osmosis** diffusion of water across a semipermeable membrane
- **osmotic pressure** the force or pressure generated by water diffusing across a semipermeable membrane, driven by differences in solute concentration across the membrane
- **osteomyelitis** inflammation of bone tissue
- **otitis externa** an infection of the external ear canal, most commonly caused by *Pseudomonas aeruginosa*; often called swimmer's ear
- **otitis** inflammation of the ear
- **otitis media with effusion** accumulation of fluid inside the middle ear with or without infection
- **Ouchterlony assay** test in which antigen and antisera are added to neighboring wells in an agar gel, allowing visualization of precipitin arcs
- **outer membrane** a phospholipid bilayer external to the peptidoglycan layer found in gram-negative cell walls
- **oxazolidinones** class of synthetic protein synthesis inhibitors that interfere with formation of the initiation complex for translation and prevent translocation of the growing protein from the ribosomal A site to the P site
- **oxidation reaction** chemical reaction that removes electrons (often as part of H atoms) from donor molecules, leaving them oxidized
- **oxidative phosphorylation** mechanism for making ATP that uses the potential energy stored within an electrochemical gradient to add P_i to ADP
- **oxygenic photosynthesis** type of photosynthesis found in plants, algae, and cyanobacteria, and in which H₂O is used as the electron donor to replace an electron lost by a reaction center pigment, resulting in oxygen as a byproduct

P

- **P (peptidyl) site** functional site of an intact ribosome that binds charged tRNAs carrying amino acids that have formed peptide bonds

with the growing polypeptide chain but have not yet dissociated from their corresponding tRNA

- **palatine tonsil** lymphoid tissue located near the oropharynx
- **pandemic disease** an epidemic that is worldwide as opposed to regional
- **papilloma** growth on the skin associated with infection by any of the human papilloma viruses (HPV); commonly known as a wart
- **paracrine function** refers to a cytokine signal released from a cell to a receptor on a nearby cell
- **parasitism** type of symbiosis in which one population benefits while harming the other parasitology the study of parasites
- **parenteral route** means of entry by a pathogen through skin or mucous membranes when these barriers are breached
- **paroxysmal stage** most serious stage of pertussis (whooping cough), characterized by severe and prolonged coughing spells
- **passive carrier** an individual capable of transmitting a pathogen to another individual without becoming infected
- **passive immunity** adaptive immune defenses received from another individual or animal
- **pasteurization** form of microbial control using heat that is applied to foods; kills pathogens and reduces the number of spoilage-causing microbes while maintaining food quality
- **pathogen** a disease-causing microorganism
- **pathogen-associated molecular patterns (PAMPs)** common molecular motifs found on pathogens
- **pathogenicity** ability of a microbial agent to cause disease
- **pattern recognition receptors (PRRs)** receptors on the surface or in the interior of phagocytic cells that bind to pathogen-associated molecular patterns (PAMPs)
- **pellicle** structure that underlies the plasma membrane in protists, providing additional support
- **pelvic inflammatory disease (PID)** infection of the female reproductive organs that may spread from the vagina to the cervix, uterus, fallopian tubes, and ovaries
- **penetration** entry of phage or virus into a host cell through injection, endocytosis, or membrane fusion

- **penicillin** β -lactam antibacterial that was the first cell wall synthesis inhibitor developed
- **penis** external genital organ in males through which urine and semen are discharged
- **pentamidine** antiprotozoan drug that appears to degrade kDNA in target cells, as well as inhibit protein synthesis
- **pentose phosphate pathway (PPP)** alternative glycolytic pathway that produces intermediates used for the biosynthesis of nucleotides and amino acids; also called the *phosphogluconate pathway* or the *hexose monophosphate shunt*
- **peptic ulcer** an ulcer in the lining of the stomach or duodenum, often associated with *Helicobacter pylori*
- **peptide bond** bond between the carboxyl group of one amino acid and the amine group of another; formed with the loss of a water molecule
- **peptidoglycan (murein)** the polymer of alternating N-acetylmuramic acid NAM and N-acetylglucosamine (NAG) subunits linked together by peptide chains; a major constituent of bacterial cell walls
- **peptidyl transferase** RNA-based ribozyme that is part of the 50S ribosomal subunit and catalyzes formation of the peptide bond between the amino acid bound to a tRNA and the growing polypeptide chain
- **perforin** compound released from a natural killer cell that creates pores in the target cell through which other toxins (particularly granzymes) can gain access to the cytoplasm
- **pericarditis** inflammation of the sac that surrounds the heart
- **period of convalescence** fifth stage of acute disease, during which the patient returns to normal function
- **period of decline** fourth stage of disease, during which the number of pathogens present in the host decreases, along with signs and symptoms of disease
- **period of illness** third stage of acute disease, during which the number of pathogens present in the host is greatest and the signs and symptoms of disease are most severe
- **periodontal disease** a condition in which the gums are inflamed and may erode
- **periodontitis** inflammation of the gums that is more severe than gingivitis, spreading deeper into the tissues

- **peripheral nervous system** network of neurons that connects the CNS with organs, sensory organs, and muscles throughout the body
- **peripheral tolerance** mechanism by which regulatory T cells inhibit self-reactive immune responses in T cells that have already exited the thymus
- **periplasmic space** the space between the cell wall and the plasma membrane, primarily in gram-negative bacteria
- **peristalsis** muscular contractions of the gastrointestinal tract that propel ingested material through the stomach, intestines, and, eventually, through the rectum and out of the body
- **peritrichous** having numerous flagella covering the entire surface of a bacterial cell
- **peroxidase** enzyme that catalyzes the detoxification of peroxides
- **peroxisome** in eukaryotic cells, a membrane-bound organelle (not part of the endomembrane system) that produces hydrogen peroxide to break down various types of molecules; also plays a role in lipid biosynthesis
- **peroxygen** type of strong oxidizing agent that causes free radical formation in cells; can be used as a disinfectant or antiseptic
- **persister** dormant cell that survives in the death phase and is resistant to most antibiotics
- **pertussis** contagious illness caused by *Bordetella pertussis* that causes severe coughing fits followed by a whooping sound during inhalation; commonly known as whooping cough
- **pertussis toxin** main virulence factor accounting for the symptoms of whooping cough
- **petechiae** small red or purple spots on the skin that result from blood leaking out of damaged vessels
- **Petroff-Hausser counting chamber** calibrated slide that allows counting of bacteria in a specific volume under a microscope
- **Peyer's patches** lymphoid tissue in the ileum that monitors and fights infections
- **phagemid** a plasmid capable of being replicated as a plasmid and also incorporated into a phage head
- **phagocytosis** a type of endocytosis in which large particles are engulfed by membrane invagination, after which the particles are

enclosed in a pocket, which is pinched off from the membrane to form a vacuole

- **phagolysosome** compartment in a phagocytic cell that results when the phagosome is fused with the lysosome, leading to the destruction of the pathogens inside
- **phagosome** compartment in the cytoplasm of a phagocytic cell that contains the phagocytosed pathogen enclosed by part of the cell membrane
- **pharmacogenomics (toxicogenomics)** the evaluation of the effectiveness and safety of drugs on the basis of information from an individual's genomic sequence as well as examination of changes in gene expression in response to the drug
- **pharyngitis** inflammation of the pharynx
- **pharynx** region connecting the nose and mouth to the larynx: the throat
- **phase-contrast microscope** a light microscope that uses an annular stop and annular plate to increase contrast
- **phenol coefficient** measure of the effectiveness of a chemical agent through comparison with that of phenol on *Staphylococcus aureus* and *Salmonella enterica* serovar Typhi
- **phenolics** class of chemical disinfectants and antiseptics characterized by a phenol group that denatures proteins and disrupts membranes
- **phenotype** observable characteristics of a cell or organism
- **phosphodiester bonds** linkage whereby the phosphate group attached to the 5' carbon of the sugar of one nucleotide bonds to the hydroxyl group of the 3' carbon of the sugar of the next nucleotide
- **phosphogluconate pathway** see *pentose phosphate pathway*
- **phospholipase** enzyme that degrades phospholipids
- **phospholipid** complex lipid that contains a phosphate group
- **phospholipid-derived fatty acids (PLFA) analysis** technique in which membrane phospholipids are saponified to release the fatty acids of the phospholipids, which can be subjected to FAME analysis for identification purposes
- **phosphorescence** the ability of certain materials to absorb energy and then release that energy as light after a delay
- **photosynthesis** process whereby phototrophic organisms convert solar energy into chemical energy that can then be used to build

carbohydrates

- **photosynthetic pigment** pigment molecule used by a cell to absorb solar energy; each one appears the color of light that it transmits or reflects
- **photosystem** organized unit of pigments found within a photosynthetic membrane, containing both a light-harvesting complex and a reaction center
- **phototaxis** directional movement using flagella in response to light
- **phototroph** organism that gets its energy from light
- **phototrophic bacteria** nontaxonomic group of bacteria that use sunlight as their primary source of energy
- **phylogeny** the evolutionary history of a group of organisms
- **phytoplankton** photosynthetic plankton
- **pia mater** fragile and innermost membrane layer surrounding the brain
- **pili** long protein extensions on the surface of some bacterial cells; specialized F or sex pilus aids in DNA transfer between cells
- **pinocytosis** a type of endocytosis in which small dissolved materials are endocytosed into smaller vesicles
- **plague** infectious epidemic disease caused by *Yersinia pestis*
- **plankton** microscopic organisms that float in the water and are carried by currents; they may be autotrophic (phytoplankton) or heterotrophic (zooplankton)
- **planktonic** free-floating or drifting in suspension
- **plantibodies** monoclonal antibodies produced in plants that are genetically engineered to express mouse or human antibodies
- **plaque** clear area on bacterial lawn caused by viral lysis of host cells
- **plasma cell** activated and differentiated B cell that produces and secretes antibodies
- **plasma** fluid portion of the blood that contains all clotting factors
- **plasma membrane** (also called the cell membrane or cytoplasmic membrane) lipid bilayer with embedded proteins that defines the boundary of the cell
- **plasmalemma** protist plasma membrane
- **plasmid** small, circular, double-stranded DNA molecule that is typically independent from the bacterial chromosome
- **plasmolysis** the separation of the plasma membrane away from the cell wall when a cell is exposed to a hypertonic environment

- **platelets** cell fragments in the peripheral blood that originate from megakaryocyte cells in the bone marrow; also called thrombocytes
- **Platyhelminthes** phylum comprising flatworms
- **pleconaril** an antiviral drug targeting picornaviruses that prevents the uncoating of virus particles upon their infection of host cells
- **pleomorphic** able to change shape
- **pneumococcal meningitis** bacterial infection caused by *Streptococcus pneumoniae* that results in an inflammation of the meninges
- ***Pneumocystis pneumonia*** common pulmonary infection in patients with AIDS; caused by *P. jirovecii*
- **pneumonia** pulmonary inflammation that causes the lungs to fill with fluids
- **pneumonic plague** rare form of plague that causes massive hemorrhages in the lungs and is communicable through aerosols
- **point mutation** mutation, most commonly a base substitution, that affects a single base pair
- **point source spread** a form of common source spread in which the transmission of a disease from the source occurs for a brief period that is less than the pathogen's incubation period
- **polar tubule** a tube-like structure produced by spores of parasitic Microsporidia fungi that pierces host cell membranes
- **poliomyelitis (polio)** disease caused by an infection of the enteric polio virus characterized by inflammation of the motor neurons of the brain stem and spinal cord; can result in paralysis
- **poly-A tail** string of approximately 200 adenine nucleotides added to the 3' end of a eukaryotic primary mRNA transcript to stabilize it
- **polyacrylamide gel electrophoresis (PAGE)** a method for separating populations of proteins and DNA fragments during Sanger sequencing of varying sizes by differential migration rates caused by a voltage gradient through a vertical gel matrix
- **polycistronic mRNA** single mRNA molecule commonly produced during prokaryotic transcription that carries information encoding multiple polypeptides
- **polyclonal antibodies** antibodies produced in a normal immune response, in which multiple clones of B cells respond to many different epitopes on an antigen

- **polyenes** class of antifungal drugs that bind to ergosterol to form membrane pores, disrupting fungal cell membrane integrity
- **polyhedral virus** virus with a three-dimensional shape with many facets
- **polyhydroxybutyrate (PHB)** a type of cellular inclusion surrounded by a phospholipid monolayer embedded with protein
- **polylinker site** or **multiple cloning site (MCS)** a short sequence containing multiple unique restriction enzyme recognition sites that are used for inserting foreign DNA into the plasmid after restriction digestion of both the foreign DNA and the plasmid
- **polymer** macromolecule composed of individual units, monomers, that bind together like building blocks.
- **polymerase chain reaction (PCR)** an *in vitro* molecular technique that rapidly amplifies the number of copies of specific DNA sequences to make the amplified DNA available for other analyses
- **polymorphonuclear neutrophil (PMN)** see *neutrophils*
- **polymyxins** lipophilic polypeptide antibiotics that target the lipopolysaccharide component of gram-negative bacteria and ultimately disrupt the integrity of their outer and inner membranes
- **polypeptide** polymer having from approximately 20 to 50 amino acids
- **polyphyletic** refers to a grouping of organisms that is not descended from a single common ancestor
- **polyribosome (polysome)** structure including an mRNA molecule that is being translated by multiple ribosomes concurrently
- **polysaccharide** polymer composed of hundreds of monosaccharides linked together by glycosidic bonds; also called *glycans*
- **portal of entry** anatomical feature of the body through which pathogens can enter host tissue
- **portal of exit** anatomical feature of the body through which pathogens can leave diseased individual
- **positive (+) strand** viral RNA strand that acts like messenger RNA and can be directly translated inside the host cell
- **positive stain** a stain that colors the structure of interest
- **pour plate method** a technique used for inoculating plates with diluted bacterial samples for the purpose of cell counting; cells are mixed with warm liquid agar before being poured into Petri dishes

- **praziquantel** antihelminthic drug that induces a calcium influx into tapeworms, leading to spasm and paralysis
- **precipitin** complex lattice of antibody and antigen that becomes too large to stay in solution
- **precipitin ring test** assay in which layers of antisera and antigen in a test tube form precipitin at the interface of the two solutions
- **prevalence** the total number or proportion of individuals in a population ill with a specific disease
- **primary amoebic meningoencephalitis (PAM)** acute and deadly parasitic infection of brain tissues by the amoeba *Naegleria fowleri*
- **primary antibody** in a sandwich ELISA, the antibody that is attached to wells of a microtiter plate to capture antigen from a solution, or in an indirect ELISA, the antigen-specific antibody present in a patient's serum
- **primary cell culture** cells taken directly from an animal or plant and cultured in vitro
- **primary immunodeficiency** genetic condition that results in impaired immune function
- **primary infection** initial infection produced by a pathogen
- **primary lymphoid tissue** one of two types of lymphatic tissue; comprises bone marrow and the thymus
- **primary pathogen** microorganism that can cause disease in the host regardless of the effectiveness of the host's immune system
- **primary response** the adaptive immune response produced upon first exposure to a specific antigen
- **primary stain** refers, in differential staining techniques, to the first dye added to the specimen
- **primary structure** bonding sequence of amino acids in a polypeptide chain **protein** macromolecule that results when the number of amino acids linked together becomes very large, or when multiple polypeptides are used as building subunits
- **primary transcript** RNA molecule directly synthesized by RNA polymerase in eukaryotes before undergoing the additional processing required to become a mature mRNA molecule
- **primase** RNA polymerase enzyme that synthesizes the RNA primer required to initiate DNA synthesis

- **primer** short complementary sequence of five to 10 RNA nucleotides synthesized on the template strand by primase that provides a free 3'-OH group to which DNA polymerase can add DNA nucleotides
- **prion** acellular infectious particle consisting of just proteins that can cause progressive diseases in animals and humans
- **prodromal period** second stage of acute disease, during which the pathogen continues to multiply in the host and nonspecific signs and symptoms become observable
- **progeny virus** newly assembled virions ready for release outside the cell
- **proglottid** body segment of a cestode (tapeworm)
- **prokaryote** an organism whose cell structure does not include a membrane-bound nucleus
- **prokaryotic cell** a cell lacking a nucleus bound by a complex nuclear membrane
- **promoter** DNA sequence onto which the transcription machinery binds to initiate transcription
- **propagated spread** the progression of an infectious disease from person to person, either indirectly or directly, through a population of susceptible individuals as one infected individual transmits the agent to others, who transmit it to others yet again
- **prophage** phage genome that has incorporated into the host genome
- **prospective study** a research design that follows cases from the beginning of the study through time to associate measured variables with outcomes
- **prostate gland** gland that contributes fluid to semen
- **prostatitis** inflammation of the prostate gland
- **protease** enzyme involved in protein catabolism that removes individual amino acids from the ends of peptide chains
- **protease inhibitor** class of antiviral drugs, used in HIV therapy and hepatitis C therapy, that inhibits viral-specific proteases, preventing viral maturation
- **protein signature** an array of proteins expressed by a cell or tissue under a specific condition
- **Proteobacteria** phylum of gram-negative bacteria
- **proteomic analysis** study of all accumulated proteins of an organism

- **proteomics** the study of the entire complement of proteins in an organism; involves monitoring differences in gene expression patterns between cells at the protein level
- **protists** informal name for diverse group of eukaryotic organisms, including unicellular, colonial, and multicellular types that lack specialized tissues
- **proton motive force** electrochemical gradient formed by the accumulation of hydrogen ions (also known as protons) on one side of a membrane relative to the other
- **protozoan** (plural: protozoa) a unicellular eukaryotic organism, usually motile
- **protozoology** the study of protozoa
- **provirus** animal virus genome that has integrated into the host chromosome
- **pseudohyphae** short chains of yeast cells stuck together
- **pseudomembrane** grayish layer of dead cells, pus, fibrin, red blood cells, and bacteria that forms on mucous membranes of the nasal cavity, tonsils, pharynx, and larynx of individuals with diphtheria
- **pseudomembranous colitis** inflammation of the large intestine with the formation of a pseudomembrane; caused by *C. difficile*
- **pseudopodia** temporary projections involved in amoeboid movement; these “false feet” form by gel-sol cycling of actin polymerization/depolymerization
- **psittacosis** zoonotic *Chlamydia* infection from birds that causes a rare form of pneumonia
- **psoriasis** autoimmune disease involving inflammatory reactions in and thickening of skin
- **psychrophile** a microorganism that grows best at cold temperatures; most have an optimum growth temperature of about 15 °C and can survive temperatures below 0 °C; most cannot survive temperatures above 20 °C
- **psychrotroph** a microorganism that grows best at cool temperatures, typically between about 4 °C and 25 °C, with optimum growth at about 20 °C
- **puerperal sepsis** sepsis associated with a bacterial infection incurred by a woman during or after childbirth

- **purines** nitrogenous bases containing a double-ring structure with a six-carbon ring fused to a five-carbon ring; includes adenine and guanine
- **purple nonsulfur bacteria** phototrophic bacteria that are similar to purple sulfur bacteria except they use hydrogen rather than hydrogen sulfide for oxidation
- **purple sulfur bacteria** phototrophic bacteria that oxidize hydrogen sulfide into elemental sulfur and sulfuric acid; their purple color is due to the pigments bacteriochlorophylls and carotenoids
- **purulent** an infection that produces pus; suppurative
- **pus** accumulation of dead pathogens, neutrophils, tissue fluid, and other bystander cells that may have been killed by phagocytes at the site of an infection
- **pyelonephritis** an infection of one or both kidneys
- **pyocyanin** blue pigments produced by some strains of *Pseudomonas aeruginosa*
- **pyoderma** any suppurative (pus-producing) infection of the skin
- **pyoverdinin** a water-soluble, yellow-green or yellow-brown pigment produced by some strains of *Pseudomonas aeruginosa*
- **pyrimidines** nitrogenous bases containing a single six-carbon ring; includes cytosine and thymine in DNA
- **pyrophosphate (PPi)** two connected phosphate groups in solution
- **pyuria** pus or white blood cells in the urine

Q

- **Q fever** highly infectious zoonotic disease caused by *Coxiella burnetii* that farmers can contract from their animals by inhalation
- **quarantine** the isolation of an individual for the purpose of preventing the spread of disease
- **quaternary ammonium salts (quats)** group of cationic detergents, named for the characteristic quaternary nitrogen atom that confers a positive charge, that make up an important class of disinfectants and antiseptics
- **quaternary structure** structure of protein complexes formed by the combination of several separate polypeptides or subunits

- **quinolines** class of antiprotozoan drugs long used for the treatment of malaria; interferes with heme detoxification
- **quorum sensing** cell-to-cell communication in bacteria; enables a coordinated response from cells when the population reaches a threshold density

R

- **R plasmid** plasmid containing genes encoding proteins that make a bacterial cell resistant to one or more antibiotics
- **rabies** contagious viral disease primarily transmitted by the bite of infected mammals that can cause acute encephalitis resulting in madness, aggressiveness, coma, and death
- **radial immunodiffusion** precipitin reaction in which antigen added to a well in an antiserum-impregnated gel diffuses, producing a precipitin ring whose diameter squared is directly proportional to antigen concentration
- **rat-bite fever** relapsing fever caused by either *Bacillus moniliformis* or *Spirillum minor*; can be transmitted by the bite of a rat or through contact with rat feces or urine
- **reaction center** protein complex in a photosystem, containing a pigment molecule that can undergo oxidation upon excitation by a light-harvesting pigment, actually giving up an electron
- **reactivation tuberculosis** secondary infection by *Mycobacterium tuberculosis* that forms later in life; occurs when the bacteria escape from the Ghon complexes and establish focal infections at other sites in immunocompromised individuals
- **reactive oxygen species (ROS)** unstable and toxic ions and molecules derived from partial reduction of oxygen
- **reading frame** way nucleotides in mRNA are grouped into codons
- **real-time PCR (quantitative PCR, qPCR)** a variant of PCR involving the use of fluorescence to allow for the monitoring of the increase in double-stranded template during a PCR reaction as it occurs, allowing for the quantitation of the original target sequence
- **receptor-mediated endocytosis** a type of endocytosis in which extracellular ligands are targeted to specific cells through their binding

to specific cell surface receptors

- **recognition site** a specific, often palindromic, DNA sequence recognized by a restriction enzyme that is typically four to six base pairs long and reads the same in the 5' to 3' direction on one strand as it does in the 5' to 3' direction on the complementary strand
- **recombinant DNA molecule** a DNA molecule resulting from the cutting and insertion of DNA from one organism into the DNA of another organism, resulting in a new combination of genetic material
- **recombinant DNA pharmaceuticals** pharmaceuticals produced as a result of genetic engineering
- **recombinant DNA technology** the process by which DNA from one organism is cut and new pieces of foreign DNA from a second organism are inserted, artificially creating new combinations of genetic material within the organism
- **redox potential** tendency for a molecule to acquire electrons and become reduced; electrons flow from molecules with lower redox potentials to those with higher redox potentials
- **redox reaction** pairing of an oxidation reaction with a reduction reaction
- **reduction reaction** chemical reaction that adds electrons to acceptor molecules, leaving them reduced
- **reemerging infectious disease** a disease that was once under control or largely eradicated that has begun causing new outbreaks due to changes in susceptible populations, the environment, or the pathogen itself
- **reflection** when light bounces back from a surface
- **refraction** bending of light waves, which occurs when a light wave passes from one medium to another
- **refractive index** a measure of the magnitude of slowing of light waves by a particular medium
- **regulatory T cells** class of T cells that are activated by self-antigens and serve to inhibit peripheral self-reacting T cells from causing damage and autoimmunity
- **rejection** process by which adaptive immune responses recognize transplanted tissue as non-self, mounting a response that destroys the tissue or leads to the death of the individual

- **relapsing fever** louse- or tickborne disease caused by *Borrelia recurrentis* or *B. hermsii* and characterized by a recurrent fever
- **replica plating** plating technique in which cells from colonies growing on a complete medium are inoculated onto various types of minimal media using a piece of sterile velvet, ensuring that the orientation of cells deposited on all plates is the same so that growth (or absence thereof) can be compared between plates
- **replication bubble** circular structure formed when the DNA strands are separated for replication
- **replication fork** Y-shaped structure that forms during the process of replication as DNA unwinds and opens up to separate the DNA strands
- **replication** process by which DNA is copied
- **reporter genes** genes that encode easily observable characteristics, allowing for their expression to be easily monitored
- **repressible operon** bacterial operon, that typically containing genes encoding enzymes required for a biosynthetic pathway and that is expressed when the product of the pathway continues to be required but is repressed when the product of the pathway accumulates, removing the need for continued expression
- **repressor** protein that suppresses transcription of a gene or operon in response to an external stimulus
- **reservoir** a living host or nonliving site in which a pathogenic organism can survive or multiply
- **resident microbiota** microorganisms that constantly live in the human body
- **resolution** the ability to distinguish between two points in an image
- **restriction endonuclease (restriction enzyme)** bacterial enzyme that cuts DNA fragments at a unique, often palindromic, recognition site; used in genetic engineering for splicing DNA fragments together into recombinant molecules
- **restriction fragment length polymorphism (RFLP)** a genetic variant identified by differing numbers or sizes of DNA fragments generated after digestion of a DNA sample with a restriction endonuclease; the variants are caused by the loss or gain of restriction sites, or the insertion or deleting of sequences between restriction sites.
- **retort** large industrial autoclave used for moist heat sterilization on a large scale

- **retrospective study** a research design that associates historical data with present cases
- **retrovirus** positive ssRNA virus that produces and uses reverse transcriptase to make an ssDNA copy of the retroviral genome that can then be made into dsDNA and integrate into the host cell chromosome to form a provirus within the host chromosome.
- **reverse transcriptase** enzyme found in retroviruses that can make a copy of ssDNA from ssRNA
- **reverse transcriptase inhibitor** classes of antiviral drugs that involve nucleoside analog competitive inhibition and non-nucleoside noncompetitive inhibition of the HIV reverse transcriptase
- **reverse transcriptase PCR (RT-PCR)** a variation of PCR used to obtain DNA copies of a specific mRNA molecule that begins with the conversion of mRNA molecules to cDNA by the enzyme reverse transcriptase
- **Reye syndrome** potentially life-threatening sequelae to some viral infections that result in the swelling of the liver and brain; aspirin use has also been linked to this syndrome
- **Rh factor** red blood cell surface antigen that can trigger type II hypersensitivity reactions
- **rheostat** a dimmer switch that controls the intensity of the illuminator on a light microscope
- **rheumatic fever** serious clinical sequela of an infection with *Streptococcus pyogenes* that can result in damage to joints or the valves of the heart
- **rheumatoid arthritis** systemic autoimmune disease in which immune complexes form and deposit in the joints and their linings, leading to inflammation and destruction
- **rhinitis** inflammation of the nasal cavity
- **rhizines** structures made of hyphae found on some lichens; aid in attachment to a surface
- **ribonucleic acid (RNA)** single-stranded nucleic acid composed of ribonucleotides; important in transcription and translation (protein synthesis)
- **ribonucleotides** RNA nucleotides containing ribose as the pentose sugar component and a nitrogenous base
- **ribosome** a complex intracellular structure that synthesizes proteins

- **riboswitch** small region of noncoding RNA found within the 5' end of some prokaryotic mRNA molecules that may bind to a small intracellular molecule, influencing the completion of transcription and/or translation
- **ribulose biphosphate carboxylase (RuBisCO)** first enzyme of the Calvin cycle responsible for adding a CO₂ molecule onto a five-carbon ribulose biphosphate (RuBP) molecule
- **rifampin** semisynthetic member of the rifamycin class that blocks bacterial RNA polymerase activity, inhibiting transcription
- **rimantadine** antiviral drug that targets the influenza virus by preventing viral escape from endosomes upon host cell uptake, preventing viral RNA release and subsequent viral replication
- **ringworm** a tinea (cutaneous mycosis of the skin), typically characterized by a round, red, slightly raised lesion that heals outward from the center, giving it the appearance of a round worm
- **RNA interference (RNAi)** process by which antisense RNAs or small interfering RNAs (siRNAs) interfere with gene expression by binding to mRNA, preventing translation and protein synthesis
- **RNA polymerase** enzyme that adds nucleotides to the 3'-OH group of the growing mRNA molecule that are complementary to the template strand, forming covalent phosphodiester bonds between the nucleotides in the RNA
- **RNA splicing** process of removing intron-encoded RNA sequences from eukaryotic primary transcripts and reconnecting those encoded by exons
- **RNA transcript** mRNA produced during transcription
- **Rocky Mountain spotted fever** potentially fatal tickborne disease caused by *Rickettsia rickettsii* characterized by fever, body aches, and a rash
- **rogue form** misfolded form of the PrP protein that is normally found in the cell membrane and has the tendency to aggregate in neurons, causing extensive cell death and brain damage
- **rolling circle replication** type of rapid unidirectional DNA synthesis of a circular DNA molecule
- **roseola** a rash-causing illness, most commonly affecting children, associated with human herpesvirus 6 (HHV-6)

- **rough endoplasmic reticulum** a type of endoplasmic reticulum containing bound 80S ribosomes for the synthesis of proteins destined for the plasma membrane
- **route of administration** method used to introduce a drug into the body
- **rRNA** type of stable RNA that is a major constituent of ribosomes, ensuring proper alignment of the mRNA and the ribosomes as well as catalyzing the formation of the peptide bonds between two aligned amino acids during protein synthesis
- **rubella** German measles, caused by the rubella virus
- **runs (running)** purposeful, directional movement of a prokaryotic cell propelled by counterclockwise flagellar rotation

S

- **σ factor** subunit of bacterial RNA polymerase conferring promoter specificity that can be substituted with a different version in response to an environmental condition, allowing for a quick and global change of the regulon transcribed
- **saccharide** carbohydrate
- **salmonellosis** gastrointestinal illness caused by *Salmonella* bacteria
- **salpingitis** inflammation of the fallopian tubes
- **sandwich ELISA** EIA in which the primary antibody is first attached to the wells of a microtiter plate, allowing it to capture antigen from an unknown solution to be quantified
- **Sanger DNA sequencing (dideoxy method, chain termination method)** the original DNA sequencing technique in which dideoxy nucleotides, each labeled with a molecular beacon, are used to terminate chain elongation; the resulting incrementally sized fragments are then separated by electrophoresis to determine the sequence of the DNA molecule
- **sanitization** protocol that reduces microbial load on inanimate surfaces to levels deemed safe for public health
- **saprozoic** refers to protozoans that ingest small, soluble food molecules

- **SARS** severe acute respiratory syndrome; caused by a zoonotic coronavirus that results in flu-like symptoms
- **saturated fatty acid** lipid with hydrocarbon chains containing only single bonds, which results in the maximum number of hydrogen atoms per chain
- **scanning electron microscope (SEM)** a type of electron microscope that bounces electrons off of the specimen, forming an image of the surface
- **scanning probe microscope** a microscope that uses a probe that travels across the surface of a specimen at a constant distance while the current, which is sensitive to the size of the gap, is measured
- **scanning tunneling microscope** a microscope that uses a probe that is passed just above the specimen as a constant voltage bias creates the potential for an electric current between the probe and the specimen
- **scarlet fever** bacterial infection caused by *Streptococcus pyogenes*, marked by a high fever and a disseminated scarlet rash
- **schistosomiasis** helminthic infection caused by *Schistosoma* spp.; transmitted from a snail intermediate host to human swimmers or bathers in freshwater
- **schizogony** asexual reproduction in protozoans that is characterized by multiple cell divisions (one cell dividing to form many smaller cells)
- **scolex** the head region of a cestode (tapeworm), which typically has suckers and/or hooks for attachment to the host
- **scrapie** form of transmissible spongiform encephalopathy that primarily affects sheep
- **sebaceous gland** a gland located in hair follicles that secretes sebum
- **sebum** lipid-rich substance secreted by the sebaceous glands of the skin
- **secondary antibody** antibody to which an enzyme is attached for use in ELISA assays; in direct and sandwich ELISAs, it is specific for the antigen being quantified, whereas in indirect ELISA, it is specific for the primary antibody
- **secondary immunodeficiency** impaired immune response due to infection, metabolic disturbance, poor diet, stress, or other acquired factors
- **secondary infection** second infection that develops after a primary infection as a result of the primary disease compromising immune

- defenses or antibiotics, thus eliminating protective microbiota
- **secondary lymphoid tissue** one of two types of lymphatic tissue; comprises the spleen, lymph nodes, Peyer's patches, and mucosa associated lymphoid tissue (MALT)
 - **secondary response** the adaptive immune response produced in response to a specific antigen to which the body has previously been exposed
 - **secondary structure** structure stabilized by hydrogen bonds between the carbonyl and amine groups of a polypeptide chain; may be an α -helix or a β -pleated sheet, or both
 - **secretory vesicle** membranous sac that carries molecules through the plasma membrane to be released (secreted) from the cell
 - **selective IgA deficiency** primary immunodeficiency in which individuals produce normal levels of IgG and IgM, but are unable to produce secretory IgA
 - **selective media** media that contain additives that encourage the growth of some bacteria while inhibiting others
 - **selective toxicity** desirable quality of an antimicrobial drug indicating that it preferentially kills or inhibits the growth of the target microbe while causing minimal or no harm to the host
 - **semiconservative DNA replication** pattern of DNA replication process whereby each of the two parental DNA strands acts as a template for new DNA to be synthesized, producing hybrid old- and new-strand daughter molecules
 - **semicritical item** object that contacts mucous membranes or nonintact skin but does not penetrate tissues; requires a high level of disinfection
 - **seminal vesicles** glands that contribute fluid to semen
 - **semisynthetic antimicrobial** chemically modified derivative of a natural antibiotic
 - **sense strand** strand of DNA that is not transcribed for gene expression; it is complementary to the antisense strand
 - **sepsis** systemic inflammatory response to an infection that results in high fever and edema, causing organ damage and possibly leading to shock and death
 - **septate hyphae** hyphae that contain walls between individual cells; characteristic of some fungi
 - **septic arthritis** see *infectious arthritis*

- **septic shock** serious condition marked by the loss of blood pressure resulting from an inflammatory response against a systemic infection
- **septic** the condition of being septicemic; having an infection in the blood
- **septicemia** condition in which pathogens are multiplying in blood
- **septicemic plague** form of plague that occurs when the bacterial pathogen gains access to the bloodstream
- **septum** separating structure that forms during cell division; also describes the separating wall between cells in a filament
- **sequela (plural: sequelae)** condition that arises as a consequence of a prior disease
- **serial dilution** sequential transfer of known volumes of culture samples from one tube to another to perform a several-fold dilution of the original culture
- **seroconversion** point in an infection at which antibody to a pathogen is detectible using an immunoassay
- **serotype** strain or variation of the same species of bacteria; also called serovar
- **serovar** specific strain of bacteria identified by agglutination using strain-specific antisera
- **serum** fluid portion of the blood after clotting has occurred; generally lacks clotting factors
- **serum sickness** systemic type III hypersensitivity reaction
- **sessile** attached to a surface
- **severe combined immunodeficiency disease (SCID)** genetic disorder resulting in impaired function of B cells and T cells
- **sex pilus** specialized type of pilus that aids in DNA transfer between some prokaryotic cells
- **sheath** part of the tail on a bacteriophage that contracts to introduce the viral DNA into the bacterium
- **shigellosis** gastrointestinal illness caused by *Shigella* bacteria, also called bacillary dysentery
- **shingles** acute and painful rash that forms following the reactivation of a latent chickenpox infection
- **shock** extreme drop in blood pressure that, among other causes, can result from a strong immune response to the activity of toxins or response to bacterial products and can result in death

- **shuttle vector** a plasmid that can move between bacterial and eukaryotic cells
- **side chain** the variable functional group, R , attached to the α carbon of an amino acid
- **sign** objective and measurable indication of a disease
- **silent mutation** point mutation that results in the same amino acid being incorporated into the resulting polypeptide
- **simple microscope** a type of microscope with only one lens to focus light from the specimen
- **simple staining** a staining technique that uses a single dye
- **single-stranded binding protein** protein that coats the single strands of DNA near each replication fork to prevent the single-stranded DNA from rewinding into a double helix
- **sinusitis** inflammation of the sinuses
- **S-layer** cell envelope layer composed of protein covering the cell walls of some bacteria and archaea; in some archaea, may function as the cell wall
- **slime layer** a type of glycocalyx with unorganized layers of polysaccharides that aid bacterial adherence to surfaces
- **smear** a thin layer of a specimen on a slide
- **smooth endoplasmic reticulum** a type of endoplasmic reticulum that lacks ribosomes, is involved in the biosynthesis of lipids and in carbohydrate metabolism, and serves as the site of detoxification of toxic compounds within the cell
- **soft chancres** soft, painful ulcers associated with the STI chancroid
- **soma** cell body of a neuron
- **sonication** method of microbial control that involves application of ultrasound waves to form cavitation within a solution, including inside cells, disrupting cell components as a result
- **Southern blot** a technique in molecular genetics used to detect the presence of certain DNA sequences within a given DNA sample; DNA fragments within the sample are separated by agarose gel electrophoresis, immobilized on a membrane, and then exposed to a specific DNA probe labeled with a radioactive or fluorescent molecular beacon to aid in detection
- **specialized transduction** transfer of a specific piece of bacterial chromosomal DNA near the site of integration by the phage

- **specificity** the ability of the specific adaptive immune system to target specific pathogens or toxins
- **spike** viral glycoprotein embedded within the viral capsid or envelope used for attachment to host cells
- **spirochetes** a group of long, thin, spiral-shaped fastidious bacteria that includes the human pathogens that cause syphilis, Lyme disease, and leptospirosis
- **spleen** abdominal organ consisting of secondary lymphoid tissue that filters blood and captures pathogens and antigens that pass into it; also contains specialized macrophages and dendritic cells that are crucial for antigen presentation
- **spliceosome** protein complex containing small nuclear ribonucleoproteins that catalyzes the splicing out of intron-encoded RNA sequences from the primary transcript during RNA maturation in eukaryotes
- **spontaneous generation** the now-disproven theory that life can arise from nonliving matter
- **spontaneous mutation** mutation not caused by a mutagen that occurs through DNA replication errors
- **sporadic disease** an illness that occurs at relatively low levels with no discernible pattern or trend, frequently with no geographic focus
- **spores** specialized cells that may be used for reproduction or may be specialized to withstand harsh conditions
- **sporotrichosis** subcutaneous infection caused by the fungus *Sporothrix schenckii*, which causes skin lesions and can potentially spread to the lymphatic system; also known as rose gardener's disease or rose thorn disease
- **sporulation** the process by which a vegetative cell produces a dormant endospore
- **spread plate method** a technique used for inoculating plates with diluted bacterial samples for the purpose of cell counting; the liquid sample is pipetted onto solid medium and spread uniformly across the plate
- **St. Louis encephalitis** mosquito-borne viral infection of the brain that occurs primarily in the central and southern United States
- **stage** the platform of a microscope on which slides are placed

- **staining** the addition of stains or dyes to a microscopic specimen for the purpose of enhancing contrast
- **staphylococcal food poisoning** gastrointestinal illness caused by toxins produced by *Staphylococcus aureus*
- **staphylolysins** a class of staphylococcal exotoxins that are cytotoxic to skin cells and white blood cells
- **starch** energy-storage polysaccharide in plants; composed of two types of glucose polymers: amylose and amylopectin
- **start codon** AUG codon, specifying methionine, which is typically the codon that initiates translation
- **stationary phase** interval during which the number of cells formed by cell division is equal to the number of cells dying
- **stereoisomers** isomers that differ in the spatial arrangements of atoms
- **sterilant** strong chemical that effectively kills all microbes and viruses in or on an inanimate item
- **sterile field** specified area that is free of all vegetative microbes, endospores, and viruses
- **sterilization** protocol that completely removes all vegetative cells, endospores, and viruses from an item
- **steroid** lipid with complex, ringed structures found in cell membranes and hormones
- **sterol** the most common type of steroid; contains an OH group at one specific position on one of the molecule's carbon rings
- **sticky ends** short, single-stranded complementary overhangs that may be produced when many restriction enzymes cut DNA
- **stigma** light-sensing eyespot found in *Euglena*
- **stop codon (nonsense codon)** one of three codons for which there is no tRNA with a complementary anticodon; a signal within the mRNA for termination of translation
- **stratum corneum** a layer of dead, keratinized cells that forms the uppermost layer of the epidermis
- **strep throat (streptococcal pharyngitis)** bacterial pharyngitis caused by *Streptococcus pyogenes*
- **streptococcal toxic shock-like syndrome (STSS)** condition similar to staphylococcal toxic shock syndrome but with greater likelihood of bacteremia, necrotizing fasciitis, and acute respiratory distress syndrome

- **stroma** a gel-like fluid that makes up much of a chloroplast's volume, and in which the thylakoids float
- **strongyloidiasis** soil-transmitted intestinal infection caused by the helminth *Strongyloides stercoralis*
- **structural formula** graphic representation of the molecular structure showing how the atoms are arranged
- **structural isomers** molecules composed of the same numbers and types of atoms but with different bonding sequences
- **subacute bacterial endocarditis** form of endocarditis in which damage to the valves of the heart occurs over months as a result of blood clot formation and immune-response-induced fibrosis of the valves
- **subclinical disease** disease that does not present any signs or symptoms
- **subcutaneous mycosis** any fungal infection that penetrates the epidermis and dermis to enter deeper tissues
- **substrate** chemical reactants of an enzymatic reaction
- **substrate-level phosphorylation** direct method of ATP production in which a high-energy phosphate group is removed from an organic molecule and added to an ADP molecule
- **subunit vaccine** vaccine that contains only key antigens as opposed to whole pathogens
- **sugar-phosphate backbone** alternating sugar-phosphate structure composing the framework of a nucleic acid strand that results from phosphodiester bond formation between nucleotides
- **sulfonamides (sulfa drugs)** group of structurally related synthetic antimicrobial compounds that function as antimetabolites, competitively inhibiting an enzyme in the bacterial folic acid synthesis pathway
- **superantigen** class of exotoxin that triggers a strong nonspecific immune response with excessive production of cytokines (cytokine storm) causing inflammation, high fever, shock, and, potentially, death
- **supercoiled** extensive wrapping and twisting of a DNA molecule, allowing the DNA to fit within a small space
- **supercoiling** process in which DNA is underwound or overwound to fit inside a cell

- **supercritical fluid** molecule, commonly carbon dioxide, brought to high pressures to reach a state that has physical properties between those of liquids and gases, allowing it to effectively penetrate surfaces and cells to form carbonic acid, which lowers the pH of cells considerably, leading to sterilization
- **superinfection** secondary infection that may develop as a result of long-term, broad-spectrum antimicrobial use
- **superoxide dismutase** enzyme that catalyzes the breakdown of superoxide anions
- **suppurative** producing pus; purulent
- **surfactant** group of chemical compounds used for degerming; lower the surface tension of water, creating emulsions that mechanically carry away microorganisms
- **sweat gland** one of numerous tubular glands embedded in the dermis that secretes the watery substance known as perspiration
- **symbiosis** any interaction between different species that are associated with each other within a community
- **symptom** subjective experience of disease felt by the patient
- **synapse** junction between a neuron and another cell
- **syncytia** multinucleated cells that form from the fusion of normal cells during infections or other processes
- **syndrome** group of signs and symptoms characteristic of a particular disease
- **syngamy** process in which haploid gametes fuse
- **synthetic antimicrobial** antimicrobial developed from a chemical not found in nature
- **syphilis** an STI caused by the bacterium *Treponema pallidum*
- **systemic autoimmune disease** autoimmune disease that affect the organism as a whole, rather than a single organ
- **systemic infection** infection that has spread to multiple locations or body systems
- **systemic inflammatory response syndrome (SIRS)** severe inflammatory response to the presence of microbes in the blood; can lead to sepsis
- **systemic lupus erythematosus (SLE)** systemic autoimmune disease producing inflammatory type III hypersensitivities as antibodies form immune complexes with nuclear and cytoplasmic antigens

- **systemic mycosis** a fungal infection that spreads throughout the body

T

- **T-cell receptors (TCR)** molecules on T cells involved in the recognition of processed foreign epitopes presented with MHC I or MHC II
- **T lymphocyte** lymphocyte that serves as the central orchestrator, bridging humoral, cellular, and innate immunity, and serves as the effector cells of cellular immunity; T cell
- **taeniasis** infection caused by *Taenia* or *Diphyllbothrium*
- **tail fiber** long protein component on the lower part of a phage used for specific attachment to bacterial cell
- **tail pins** points extended at the base of a bacteriophage sheath that, along with tail fibers, lead to phage attachment to a bacterial cell
- **tapeworms** segmented, hermaphroditic, parasitic flatworms (Platyhelminthes)
- **tartar** calcified heavy plaque on teeth, also called dental calculus
- **taxonomy** the classification, description, identification, and naming of living organisms
- **T-dependent antigen** a protein antigen that is only capable of activating a B cell with the cooperation of a helper T cell
- **TDP** thermal death point is the lowest temperature at which all microorganisms are killed in a 10-minute exposure
- **TDT** thermal death time is the length of time needed to kill all microorganisms in a sample at a given temperature
- **telomerase** enzyme that attaches to the end of a linear chromosome and adds nucleotides to the 3' end of one of the DNA strands, maintaining the telomere sequence, thus preventing loss of DNA from the end of the chromosome
- **telomere** repetitive, noncoding sequence found at the end of a linear eukaryotic chromosome that protects the genes near the end of the chromosome from deletion as the DNA molecule is repeatedly replicated
- **temperate phage** bacteriophage that can incorporate viral genome into the host cell chromosome and replicate with the host cell until new

- viruses are produced; a phage that undergoes the lysogenic cycle
- **teratogenic** able to disrupt the normal development of a fetus in utero
 - **terbinafine** antifungal drug of the allylamine class that is used topically for the treatment of dermatophytic skin infections
 - **termination of DNA replication** stage of replication during which DNA replication is halted once the chromosome has been fully replicated
 - **termination of transcription** stage of transcription that occurs when RNA polymerase has reached specific DNA sequences, leading to release of the enzyme from the DNA template, freeing the RNA transcript and, thus, halting transcription
 - **termination of translation** stage of translation during which a nonsense codon aligns with the A site, signaling release factors to release of the polypeptide, leading to the dissociation of the small and large ribosomal subunits from the mRNA and from each other
 - **tertiary structure** large-scale, three-dimensional structure of a polypeptide
 - **test sensitivity** probability that a diagnostic test will find evidence of the targeted disease when the pathogen is present
 - **test specificity** probability that a diagnostic test will not find evidence of the targeted disease when the pathogen is absent
 - **testes** (singular *testis*) pair of glands located in the scrotum of males that produce sperm and testosterone
 - **tetanus** bacterial disease caused by exotoxin produced by *Clostridium tetani* that causes a rigid paralysis
 - **tetracyclines** class of protein synthesis inhibitors that bind to the 30S subunit, blocking the association of tRNAs with the ribosome during translation
 - **T_H1 cells** subtype of T cells that stimulate cytotoxic T cells, macrophages, neutrophils, and NK cells
 - **T_H17 cells** subtype of T cell that are essential for defense against specific pathogens and infections, such as chronic mucocutaneous infections with *C. albicans*
 - **T_H2 cells** subtype of T cells that stimulate B cells and direct their differentiation; also involved in directing antibody class switching
 - **thallus** body of fleshy fungi (more generally, a body without a root, stem, or leaf) that commonly co-occurs with HIV infection; the

microbes move to the lymphatic system in the groin

- **thermophile** a microorganism that grows best at warm temperatures, typically between about 50 °C and 80 °C
- **thin sections** thin slices of tissue for examination under a TEM
- **thioglycolate medium** medium designed to test the aerotolerance of bacteria; it contains a low concentration of agar to allow motile bacteria to move throughout the medium
- **thioglycolate tube culture** contains reducing medium through which oxygen diffuses from the tube opening, producing a range of oxygen environments down the length of the tube
- **thrombocytes** see *platelets*
- **thylakoids** a highly dynamic collection of membranous sacs found in the stroma of chloroplasts; site of photosynthesis
- **thymic selection** a three-step process of negative and positive selection of T cells in the thymus
- **thymine dimer** covalent linkage between two adjacent thymine bases on exposure to ultraviolet radiation
- **thymine** pyrimidine nitrogenous base found only in DNA nucleotides
- **tincture** solution of an antiseptic compound dissolved in alcohol
- **T-independent antigen** a nonprotein antigen that can activate a B cell without cooperation from a helper T cell
- **tinea** any cutaneous fungal infection caused by dermatophytes, such as tinea corporis, tinea capitis, tinea cruris, and tinea pedis
- **tinea capitis** cutaneous mycosis of the scalp; also known as ringworm of the scalp
- **tinea corporis** cutaneous mycosis of the body; also known as ringworm of the body
- **tinea cruris** cutaneous mycosis of the groin region; also known as jock itch
- **tinea pedis** cutaneous mycosis of the feet; also known as athlete's foot
- **tissue tropism** tendency of most viruses to infect only certain tissue types within a host
- **titer** concentration obtained by titration; the reciprocal of a measurement of biological activity determined by finding the dilution of an unknown (e.g., antigen-specific antibody in an antiserum) that shows the defined end-point; always expressed as a whole number
- **tolerance** lack of an anti-self immune response

- **toll-like receptors (TLRs)** pathogen recognition receptors (PRRs) that may be found on the external surface of phagocytes or facing inward in interior compartments
- **tonsillitis** inflammation of the tonsils
- **topoisomerase** type of enzyme that helps maintain the structure of supercoiled chromosomes, preventing overwinding of DNA during certain cellular processes like DNA replication
- **topoisomerase II** enzyme responsible for facilitating topological transitions of DNA, relaxing it from its supercoiled state
- **total magnification** in a light microscope is a value calculated by multiplying the magnification of the ocular by the magnification of the objective lenses
- **toxemia** presence of toxins in the blood
- **toxic shock syndrome** severe condition marked by the loss of blood pressure and blood clot formation caused by a bacterial superantigen, toxic shock syndrome toxin
- **toxigenicity** ability of a pathogen to produce toxins to cause damage to host cells
- **toxin** poison produced by a pathogen
- **toxoid vaccine** vaccine that contains inactivated bacterial toxins
- **toxoplasmosis** typically asymptomatic protozoan infection caused by *Toxoplasma* spp. and transmitted through contact with cysts in cat feces; infections in pregnant women may cause birth defects or miscarriage
- **trace element** indispensable element present in cells in lower amounts than macronutrients; also called *micronutrient*
- **trachea** also known as the windpipe, this is a stiffened tube of cartilage that runs from the larynx to the bronchi
- **trachoma** a type of conjunctivitis, caused by *Chlamydia trachomatis*, that is a major cause of preventable blindness
- **transcription bubble** region of unwinding of the DNA double helix during transcription
- **transcription factors** proteins encoded by regulatory genes that function by influencing the binding of RNA polymerase to the promoter and allowing its progression to transcribe structural genes
- **transcription** process of synthesizing RNA using the information encoded in DNA

- **transcriptomics** the study of the entire collection of mRNA molecules produced by cells; involves monitoring differences in gene expression patterns between cells at the mRNA level
- **transduction** mechanism of horizontal gene transfer in bacteria in which genes are transferred through viral infection
- **transendothelial migration** process by which circulating leukocytes exit the bloodstream via the microvascular endothelium
- **transfection** the introduction of recombinant DNA molecules into eukaryotic hosts
- **transformation** mechanism of horizontal gene transfer in bacteria in which naked environmental DNA is taken up by a bacterial cell
- **transgenic** describing an organism into which foreign DNA from a different species has been introduced
- **transient microbiota** microorganisms, sometimes pathogenic, that are only temporarily found in the human body
- **transition reaction** reaction linking glycolysis to the Krebs cycle, during which each pyruvate is decarboxylated and oxidized (forming NADH), and the resulting two-carbon acetyl group is attached to a large carrier molecule called coenzyme A, resulting in the formation of acetyl-CoA and CO₂; also called the *bridge reaction*
- **translation (protein synthesis)** process of protein synthesis whereby a ribosome decodes an mRNA message into a polypeptide product
- **transmissible spongiform encephalopathy** degenerative disease caused by prions; leads to the death of neurons in the brain
- **transmission electron microscope (TEM)** a type of electron microscope that uses an electron beam, focused with magnets, that passes through a thin specimen
- **transmittance** the amount of light that passes through a medium
- **transparency** the property of allowing light to pass through
- **transport vesicle** membranous sac that carries molecules between various components of the endomembrane system
- **transposition** process whereby a DNA sequence known as a transposon independently excises from one location in a DNA molecule and integrates elsewhere
- **transposon (transposable element)** molecule of DNA that can independently excise from one location in a DNA molecule and integrate into the DNA elsewhere

- **trench fever** louseborne disease caused by *Bartonella quintana* and characterized by high fever, body aches, conjunctivitis, ocular pain, severe headaches, and severe bone pain
- **trench mouth** a severe form of gingivitis, also called acute necrotizing ulcerative gingivitis
- **treponemal serologic tests** tests for syphilis that measure the amount of antibody directed against antigens associated with *Treponema pallidum*
- **triacylglycerol** three fatty acids chemically linked to a glycerol molecule; also called a triglyceride
- **triazoles** ergosterol biosynthesis inhibitors used to treat several types of systemic yeast infections; exhibit more selective toxicity than the imidazoles and are associated with fewer side effects
- **tricarboxylic acid cycle** see *Krebs cycle*
- **trichinosis** soil-transmitted intestinal infection caused by the nematode *Trichinella spiralis*; associated with cyst formation
- **trichomoniasis** a common STI caused by *Trichomonas vaginalis*
- **trichuriasis** intestinal infection caused by the whipworm *Trichuris trichiura*
- **triglyceride** three fatty acids chemically linked to a glycerol molecule; also called a triacylglycerol
- **trimethoprim** synthetic antimicrobial compound that functions as an antimetabolite to an enzyme in the bacterial folic acid synthesis pathway
- **tRNA** small type of stable RNA that carries the correct amino acid to the site of protein synthesis in the ribosome and base pairs with the mRNA to allow the amino acid it carries to be inserted in the polypeptide chain being synthesized
- **trophozoite** a life cycle phase in which protists are actively feeding and growing
- **tubercle** small, rounded lesion
- **tuberculosis** life-threatening form of microbial infection marked by the presence of acid-fast bacteria growing in nodules (especially in the lungs)
- **tularemia** infection of the lymphatic system by *Francisella tularensis*; also known as rabbit fever

- **tumbles (tumbling)** random, circuitous movement of a bacterial cell, propelled by clockwise flagellar rotation
- **tumor** collection or aggregate of cells; can be benign (noncancerous) or malignant (cancerous)
- **tumor-inducing (Ti) plasmid** a naturally occurring plasmid of the bacterium *Agrobacterium tumefaciens* that researchers use as a shuttle vector to introduce a desired DNA fragment into plant cells
- **turbidity** cloudiness of a culture due to refraction of light by cells and particles
- **two-photon microscope** a microscope that uses long-wavelength or infrared light to fluoresce fluorochromes in the specimen
- **tympanic membrane** also referred to as the ear drum, this structure separates the outer and middle ear
- **type 1 diabetes mellitus** hyperglycemia caused by an autoimmune disease affecting insulin production by β cells of the pancreas
- **type I hypersensitivity** rapid-onset allergic reaction due to cross-linking of antigen-specific IgE on the outside of mast cells, resulting in release of inflammatory mediators
- **type II hypersensitivity** cytotoxic reaction triggered by IgG and IgM antibodies binding to antigens on cell surfaces
- **type III hypersensitivity** inflammatory reaction induced by formation of immune complexes and their deposition in tissues and blood vessels
- **type IV hypersensitivity** delayed T-cell-mediated inflammatory reaction that takes longer to manifest than the first three hypersensitivity types, due to the need for activation of antigen-presenting cell and T-cell subsets
- **typhoid fever** serious illness caused by infection with certain serotypes of *Salmonella*

U

- **UHT pasteurization** method of pasteurization that exposes milk to ultra-high temperatures (near 140 °C) for a few seconds, effectively sterilizing it so that it can be sealed and stored for long periods without refrigeration
- **ulcer** open sore

- **ultramicrotome** a device that cuts thin sections for electron microscopy
- **unit membrane** biological membrane composed of two layers of phospholipid molecules with the nonpolar tails associating to form a hydrophobic barrier between the polar heads; also called lipid bilayer
- **unsaturated fatty acid** lipid with hydrocarbon chains containing one or more carbon-carbon double bonds and subsequently fewer than the maximum number of hydrogen atoms per chain
- **uracil** pyrimidine nitrogenous base found only in RNA nucleotides
- **ureter** duct that transports urine from the kidneys to the urinary bladder
- **ureteritis** inflammation of the ureter
- **urethra** duct through which urine passes from the urinary bladder to leave the body through the urinary meatus
- **urethritis** inflammation of the urethra
- **urinary bladder** an organ that stores urine until it is ready to be excreted
- **urinary meatus** the opening through which urine leaves the body
- **use-dilution test** a technique for determining the effectiveness of a chemical disinfectant on a surface; involves dipping a surface in a culture of the targeted microorganism, disinfecting the surface, and then transferring the surface to a fresh medium to see if bacteria will grow
- **uterus** female reproductive organ in which a fertilized egg implants and develops

V

- **vaccination** inoculation of a patient with attenuated pathogens or antigens to activate adaptive immunity and protect against infection
- **vagina** female reproductive organ that extends from the vulva to the cervix
- **vaginitis** inflammation of the vagina
- **vaginosis** an infection of the vagina caused by overgrowth of resident bacteria
- **vancomycin** cell wall synthesis inhibitor of the glycopeptide class

- **vancomycin-intermediate *Staphylococcus aureus* (VISA)** pathogen with intermediate vancomycin resistance due to increased targets for and trapping of vancomycin in the outer cell wall
- **vancomycin-resistant enterococci (VRE)** pathogens resistant to vancomycin through a target modification of peptidoglycan subunit peptides that inhibit binding by vancomycin
- **vancomycin-resistant *Staphylococcus aureus* (VRSA)** pathogen with resistance to vancomycin that has arisen as a result of the horizontal gene transfer of vancomycin resistance genes from VRE
- **variolation** the historical practice of inoculating a healthy patient with infectious material from a person infected with smallpox in order to promote immunity to the disease
- **vas deferens** pair of ducts in the male reproductive system that conduct sperm from the testes and seminal fluid to the ejaculatory duct
- **vasculitis** inflammation affecting blood vessels (either arteries or veins)
- **VDRL (Venereal Disease Research Laboratory) test** test for syphilis that detects anti-treponemal antibodies to the phospholipids produced due to the tissue destruction by *Treponema pallidum*; antibodies are detected through a flocculation reaction with cardiolipin extracted from beef heart tissue
- **vector** animal (typically an arthropod) that transmits a pathogen from one host to another host; DNA molecules that carry DNA fragments from one organism to another
- **vegetative cell** a cell that is actively growing and dividing, and does not contain an endospore
- **vehicle transmission** transfer of a pathogen between hosts via contaminated food, water, or air
- **vein** blood vessel that returns blood from the tissues to the heart for recirculation
- **vertical direct transmission** transfer of a pathogen from mother to child during pregnancy, birth, or breastfeeding
- **vertical gene transfer** transfer of genes from parent to offspring
- **viable cell** live cell; live cells are usually detected as colony-forming units
- **viable plate count** direct method of measuring microbial growth in a culture; the number of viable or live cells is usually expressed in

CFU/mL

- **viral conjunctivitis** inflammation of the conjunctiva caused by a viral infection
- **viral envelope** lipid membrane obtained from phospholipid membranes of the cell that surrounds the capsid
- **viral hemagglutination inhibition assay** assay used to quantify the amount of neutralizing antibody against a virus by showing a decrease in hemagglutination caused by a standardized amount of virus
- **viral titer** number of virions per unit volume
- **viremia** presence of virus in blood
- **viricide** chemical or physical treatment that destroys or inactivates viruses
- **virion** inert particle that is the reproductive form of a virus
- **viroid** infectious plant pathogen composed of RNA
- **virology** the study of viruses
- **virulence** degree to which an organism is pathogenic; severity of disease signs and symptoms
- **virulence factor** product of a pathogen that assists in its ability to cause infection and disease
- **virulent phage** bacteriophage for which infection leads to the death of the host cell; a phage that undergoes the lytic cycle
- **virus** an acellular microorganism, consisting of proteins and genetic material (DNA or RNA), that can replicate itself by infecting a host cell
- **virusoid** small piece of RNA associated with larger RNA of some infectious plant viruses
- **volutin** inclusions of polymerized inorganic phosphate; also called metachromatic granules
- **vulva** the female external genitalia

W

- **water activity** water content of foods or other materials
- **wavelength** the distance between one peak of a wave and the next peak

- **Weil's disease** advanced stage of leptospirosis in which the kidney and liver become seriously infected
- **West African trypanosomiasis** chronic form of African trypanosomiasis caused by *Trypanosoma brucei gambiense*
- **West Nile encephalitis** mosquito-borne disease caused by the West Nile virus (WNV) that can result in swelling of the brain and death in severe cases
- **western blot** technique used to detect the presence of a certain protein within a given protein sample in which proteins within the sample are separated by PAGE, immobilized on a membrane, and then exposed first to an antibody that binds to the protein of interest and then second to an antibody equipped with a molecular beacon that will bind to the first antibody
- **western equine encephalitis** serious but rare mosquito-borne viral infection of the brain that is found primarily in the central and western United States
- **wet mount** a slide preparation technique in which a specimen is placed on the slide in a drop of liquid
- **wheal-flare reaction** localized type I hypersensitivity reaction, involving a raised, itchy bump (wheal) and redness (flare), to injected allergen
- **whooping cough** common name for pertussis
- **wild type** phenotype of an organism that is most commonly observed in nature
- **Winterbottom's sign** acute swelling of lymph nodes at the back of the neck that is an early sign of African trypanosomiasis
- **wobble position** third position of a codon that, when changed, typically results in the incorporation of the same amino acid because of the degeneracy of the genetic code
- **World Health Organization (WHO)** international public health organization within the United Nations; monitors and communicates international public health information and coordinates international public health programs and emergency interventions

- **xenobiotic** compound synthesized by humans and introduced to an environment in much higher concentrations than expected in nature
- **xenograft** transplanted tissue from a donor that is of a different species than the recipient
- **X-linked agammaglobulinemia** genetic disorder resulting in an inability to produce antibodies
- **x-y mechanical stage knobs** knobs on a microscope that are used to adjust the position of the specimen on the stage surface, generally to center it directly above the light

Y

- **yeast** any unicellular fungus
- **yeast infection** fungal infection of the vagina typically caused by an overgrowth of resident *Candida* spp.
- **yellow fever** mild to potentially fatal mosquito-borne viral disease caused by the yellow fever virus

Z

- **Ziehl-Neelsen technique** a method of acid-fast staining that uses heat to infuse the primary stain, carbolfuchsin, into acid-fast cells
- **zone of inhibition** clear zone around a filter disk impregnated with an antimicrobial drug, indicating growth inhibition due to the antimicrobial drug
- **zoonosis** see *zoonotic disease*
- **zoonotic disease** any disease that is transmitted to humans by animals
- **zooplankton** heterotrophic plankton
- **Z-scheme** electron flow seen in noncyclic photophosphorylation in plants, algae, and cyanobacteria due to the use of both PSI and PSII
- **zygospores** spores used by Zygomycetes for sexual reproduction; they have hard walls formed from the fusion of reproductive cells from two individuals